

DuPont™ Delrin® Acetal Homopolymer Thermoplastic Resin

Molding Guide



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1. PROCESSING GUIDELINE SUMMARY

Delrin® POM thermoplastic resins and other DuPont thermoplastic resins may be processed on conventional injection molding machines using standard industry practices. Specific attention to processing details will enhance quality and productivity. This summary represents a key subset of the detailed molding information found in the remainder of this molding guide.

Drying Considerations

As a general rule, Delrin® standard grades do not require drying. However, drying for 2–4 hours at 80 °C (176 °F) in a dehumidified dryer is necessary under these conditions:

- If moisture content is above 0.2%
- When a resin container is damaged
- When the material is not properly stored in a dry place at room temperature
- When packaging stays open for a significant time

For toughened Delrin®, moisture content should be <0.05%. Dry at 4–8 hours at 80 °C (176 °F) in a dehumidified dryer.

Melt Temperatures

- For Delrin® standard grades the optimum melt temperature is at 215±5 °C (419±10 °F)
- For parts that require a very low emission behavior it is recommended to use a melt temperature of 205±5 °C (401±10 °F)
- For toughened grades it is recommended to use a melt temperature of 205±5 °C (401±10 °F)
- Processing temperatures should be matched to part size
- Excessive residence (or hold-up) times (HUT) and/or temperatures may cause degradation.

Operating Conditions

- Keep back pressure as low as possible.
- It is crucial to check that the applied screw rotation speed is low enough to avoid over-shearing. Depending on the grade, the limit for the screw rotation speed is 0.3 m/s or lower.
- Hold Pressure is key for part properties. Depending on the grade a hold pressure range of 60–110 MPa (8.7–16.0 kpsi) is recommended. As a general rule, hold pressure time should be 8 sec per mm (0.04 in) of part thickness (based on 3 mm (0.12 in) part thickness)

Hot Runner Recommendations

Delrin® is used successfully in hot runner tools at many customers for different applications. To avoid problems during the production in hot runner tools, the following guidance should be followed:

- No hold up spots can be tolerated in the hot runner.
- The use of self-insulating tips is not recommended.
- Temperatures in the hot runner system should not exceed 190 °C (374 °F)

Mold Temperatures

Using a lower mold temperature leads to shorter crystallization time (HPT), therefore, a shorter cycle time, lower mold shrinkage but higher post mold shrinkage (especially if parts are then exposed to elevated temperatures). A balance should be found depending on the temperature in use and the required dimensional precision of the molded part short and long term.

- For Delrin® standard grades, a mold temperature of 80–100 °C (176–212 °F) is recommended as good compromise.
- For high precision parts, a higher mold temperature up to 120 °C (248 °F) might be necessary.

Shrinkage Considerations

Shrinkage in semi-crystalline resins such as Delrin® is due to:

- Crystallization of the polymer
- Thermal contraction of the part as it cools to room temperature

Causes of part distortion include:

- A high level of glass orientation
- Poor mold temperature uniformity
- Large changes in wall thickness of the part

Note: High mold temperatures and thick part sections may increase shrinkage. Shrinkage in reinforced resins is controlled by glass fiber orientation, which results in different shrink rates in parallel to and perpendicular to flow directions.

2. SAFE HANDLING INFORMATION

Safety Precautions

Processing thermoplastic resins is a generally safe operation when one complies with the following processing recommendations:

A. DuPont thermoplastic resins are molded at high temperatures and contact with molten resin can inflict severe burns. At temperatures above the melting point, moisture and other gases may generate pressure which, if suddenly released, can cause the molten polymer to be violently ejected from the machine nozzle or the hot runner system.

To minimize the chance of an accident, the instructions given in this text should be followed carefully. Potential hazards must be anticipated and either eliminated or guarded against by following established procedures including the use of proper protective equipment and clothing.

Be particularly alert during purging and whenever the resin is held in the machine or hot runner system at higher than usual temperatures or for longer than usual periods of time – as in a cycle interruption. Please read and insure understanding of the sections on molding parameters thoroughly.

In purging, be sure that the high volume (booster) pump is off and that a purge shield is in place. Reduce the injection pressure and “jog” the injection forward button a few times to minimize the possibility that trapped gas in the cylinder will cause “splattering” of the resin. In the event that molten polymer does contact the skin, cool the affected area immediately with cold water or an ice pack and get medical attention for thermal burn. Do not attempt to peel the polymer from the skin.

The best practice for limiting the evolution of odors and gases is to place the purged resin immediately into a metal container of cold water.

If, during molding, there is any suspicion that gases are being formed in the cylinder, move the purge shield in place, back the nozzle away from the mold, turn off all heat except to the nozzle and nozzle adapter, and leave the machine until it cools below the melting point of the resin. With purge shield still in place, reheat the cylinder to the minimum temperature 15 °C (25 °F) greater than the resin melting point. If jogging the injection or screw rotation button does not produce melt flow, a plug exists. In that case, shut off cylinder heat as before and follow your established safety practices for removing the nozzle. A face shield and protective long sleeve gloves should be used.

B. For resins requiring drying prior to use, pay special attention to prevent burns as these resins are dried at high temperature. Contact with hot hoppers, ovens or air hose lines could result in severe burns. Insulation of these components will reduce this possibility. Similarly, for resins requiring hot mold temperatures, pay special attention to inadvertent contact with mold surfaces and cooling fluid transfer lines, as these may also present a burn risk.

Small amounts of gases and particulate matter (i.e. low molecular weight modifiers) may be released during the molding, purging, drying, regrinding, and clean-up of thermoplastic resins. We recommend that adequate local exhaust ventilation be provided during the processing of DuPont thermoplastic resins in order to meet regional requirements. It is necessary to consider the removal of dust and particles created during the distinct processes of drying, molding, purging and regrinding all while considering the maximum residence (hold-up) times and processing temperatures.

- Thermoplastic polymers can form gaseous decomposition products during long residence times (Hold-Up Times, HUT) at the maximum recommended melt temperatures.
- Adequate local exhaust ventilation should also be provided during the regrind operation.
- Adequate local exhaust ventilation must be provided during the burnout of any equipment that contains thermoplastic resin, e.g. nozzles, etc.

Refer to Proper Use of Local Exhaust Ventilation During Processing of Plastics for details.

C. Prior to cleaning of any barrel that contains thermoplastic resins, the machine should be thoroughly purged with polyethylene or polystyrene. If a thermoplastic resin is accidentally purged over the heater bands, it should be removed and not allow to degrade.

D. Pellets or granules of thermoplastic resins present a slipping hazard if spilled on the floor because of their size and shape. They should be swept up immediately and disposed of appropriately.

E. Special safety precautions when molding Delrin®

Delrin®, as well as many other thermoplastic polymers, decomposes to gaseous products when heated for a prolonged time. These gases can generate high pressures if confined. If material is not free to exit from an injection cylinder through the nozzle, it may blow back through the hopper.

In the case of Delrin® acetal resin, decomposition is almost entirely to gaseous products, so pressure build-up can be rapid. The product of decomposition is formaldehyde.

As with any acetal polymer, when overheated, Delrin® can discolor and form gaseous decomposition products, which are largely formaldehyde. Low levels of formaldehyde emissions can also occur at typical processing temperatures. Repeated exposure to formaldehyde may result in respiratory and skin sensitization in some individuals. Formaldehyde is a potential cancer hazard.

Processing toughened grades of Delrin® can release low levels of isocyanates. Repeated exposure to isocyanates may result in respiratory and skin sensitization in some individuals.

Low levels of formaldehyde may occur in the headspace of bags as received or in containers of formed parts after processing. Bags of resin or formed parts should be opened in well ventilated areas.

Use adequate local exhaust ventilation in process areas to maintain exposures below recommended control limits. Drop air shots into water to reduce emissions.

When molding Delrin®, it is important that the operator be familiar with the factors that can cause decomposition, with the danger signals that warn of this problem, and with the action that should be taken.

The information given here is based on our experience to date. It may not cover all possible situations and it is not intended as a substitute for skill and alertness of the operator.

Follow correct start-up, operating and shut-down procedures as described later in this guide.

Beware of causes of decomposition:

- High temperature—sticking temperature controller, faulty thermocouple connections, incorrect reading, burned-out heater or heater with a hot spot, or heat surges on start-up. Do not overheat. Maintain polymer melt temperature below 230 °C (446 °F).
- Cycle delay—avoid prolonged exposure at or above the recommended processing temperature. Recommended melt temperatures for injection molding and extrusion can be found on www.delrin.dupont.com.
- Hold-up areas—in cylinder, adapter, nozzle, screw tip, hot runner and check valve assembly.
- Plugged nozzle—from scrap metal or higher melting point resin, or from closed nozzle valve.
- Foreign materials
 - Additives, fillers or colorants other than those specifically recommended for use in Delrin®
 - Contaminants (especially those containing chlorine or generating acid materials) such as polyvinylchloride resin or flame retardants
 - Copper, brass, bronze or other copper alloys in contact with molten Delrin® (not in molds where the resin solidifies after each cycle)
 - Copper-based lubricants or grease for threads
 - Contaminated rework—especially rework or reprocessed resin from outside or unknown sources
 - Do not mix Delrin® grades with other Delrin® grades, nor with any other resins, without first consulting DuPont.
 - Avoid processing Delrin® on equipment that is also used for incompatible resins, particularly halogenated polymers, such as PVC or halogenated thermoplastic elastomers, or UV stabilized or flame retardant materials.

Watch for Danger Signals:

- Frothy nozzle drool
- Spitting nozzle
- Pronounced odor
- Discolored resin—brown or black streaking
- Badly splayed parts—whitish deposit on molding or mold Screw push back from gas pressure

Action Required When Any of the Danger Signals Occur:

- AVOID PERSONAL EXPOSURE—When DANGER SIGNALS are present, DO NOT look into hopper or work around nozzle as violent ejection of melt is possible.
- MINIMIZE PERSONAL EXPOSURE TO DECOMPOSITION GASES by using general and local ventilation. If necessary, leave area of machine until ventilation has reduced concentration of formaldehyde to acceptable levels. Persons sensitized to formaldehyde or having existing pulmonary disabilities should not be involved in processing Delrin®.
- FREE NOZZLE PLUG by heating with torch. If this fails, cool down cylinder, make sure PRESSURE IS RELIEVED and CAREFULLY REMOVE NOZZLE and clean.
- TAKE AIR SHOTS to cool the resin—PURGE WITH CRYSTAL POLYSTYRENE. DROP ALL MOLTEN Delrin® INTO WATER to reduce odor level.
- Turn off cylinder heaters.
- Check temperature control instruments.
- Discontinue automatic molding and run manually until job is running smoothly.
- Provide adequate means of venting feed mechanism in case of blowback.

If decomposition occurs:

1. Shut off and purge machine.
2. Minimize personal exposure to decomposition gases by using local and general ventilation.
3. If necessary, leave area of machine until ventilation has reduced concentration of formaldehyde to acceptable levels.

F. Environment and disposal of waste

DuPont supplies Safety Data Sheet (SDS) information to its customers with the initial order of a product and on the next order after a SDS is revised. SDSs should be referenced for information such as significant hazards; emergency and first aid, and release measures; storage handling and exposure control, personal protection information, product information; environmental, transport and disposal considerations; storage information; regulatory and other information.

Note: Some commercially available mold release sprays used by molders may contain ozone depleting substances. Please ensure compliance with local regulations.

3. DRYING GUIDELINES

Molded parts from Delrin® thermoplastic resins provide an outstanding combination of flexural modulus, strength, toughness, dimensional stability, and good surface appearance. However, these properties will not be achieved in finished molded parts unless the material has been properly processed. Unlike other DuPont thermoplastic resins, drying is not as critical for Delrin® standard grades. Moisture in the raw material might result in surface defects, but, in general, will not significantly affect the mechanical properties.

However, for toughened grades, this rule is not applicable; these resins are hygroscopic (absorb moisture from the atmosphere) and too-high moisture content during the processing will lead to lower mechanical properties.

- For **toughened grades**, moisture content should be <0.05%. Recommended drying conditions for these grades is 4-8 hours at 80 °C (176 °F) in a dehumidified dryer.
- For **all other grades**, drying for 2-4 hours at 80 °C (176 °F) in a dehumidified dryer is necessary in following cases:
 - If moisture is above 0.2%, or
 - When a resin container is damaged, or
 - When the material is not properly stored in a dry place at room temperature, or
 - When packaging stays open for a significant time

Additionally, grade-specific datasheets will provide the most specific information on drying recommendations. Datasheets can be obtained from our website at www.delrin.dupont.com.

The required drying can be accomplished in conventional drying equipment, when careful attention is given to equipment selection, dryer operating conditions and maintenance procedures.

Effects of Moisture

Many engineering thermoplastics such as nylons, polycarbonates, polysulfones, and polyesters, are hygroscopic. For Delrin® standard grades, moisture is less critical. Delrin® picks up lower moisture levels over a longer period of time compared to other thermoplastics. Furthermore, the absorbed moisture does not create hydrolysis during the processing. Nevertheless, moisture can lead to surface defects on the parts.

Delrin® grades containing hygroscopic additives like toughener are more sensitive to moisture and need to be dried prior processing. Molding of Delrin® toughened compositions with excessive moisture (>0.05%) has a negative effect on toughness.

Virgin resin is shipped in bags or boxes that are designed to reduce the rate of moisture absorption, but not stop it. Resin from opened packages and regrind generally have higher moisture content, which requires them to be dried longer than resin from unopened packages.

Moisture Absorption

The water absorption rate of standard Delrin® grades is shown in **Figure 3.1**. For toughened grades, the moisture pick up is faster. At 23 °C (73 °F) and 50% RH, a highly-toughened Delrin® picks up 0.1% moisture in 4 hr; at 30 °C (86 °F) and 85% RH it will pick up 0.3% moisture in 2 hr. Given this, drying is highly recommended. In **Figure 3.2**, the drying behavior of a highly toughened grade is shown.

Figure 3.1 Rate of Water Absorption at Various Conditions for Delrin® Standard Grades

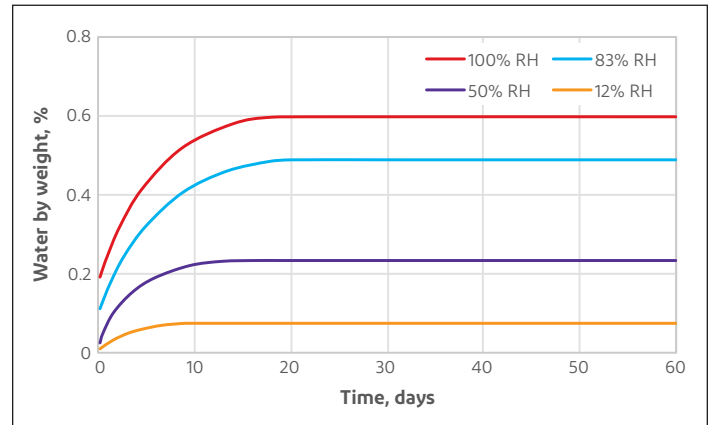
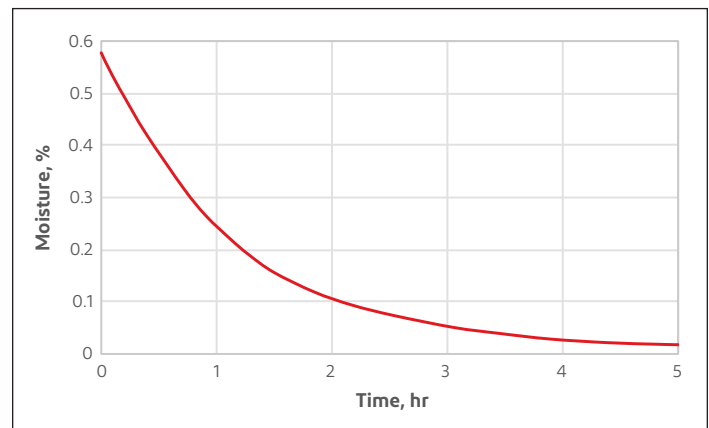


Figure 3.2 Drying Behavior of Super-Toughened Delrin® at 80 °C (176 °F) and a Dew Point of -23 °C (-9 °F)



Dryer Conditions

Properly operating desiccant-dehumidified-air or vacuum hopper dryers can dry thermoplastic resin adequately in a short period of time. Dehumidified or vacuum hopper dryer systems are necessary for successful drying of thermoplastic resins.

There are four critical parameters for dehumidified air systems: air flow, air temperature, air dew point, and time. The ideal air flow rate is determined by each kilogram (or pound) per hour of resin processed. For each kilogram (or pound) per hour that is processed, 3.0–3.7 m³ per kilogram per hour (or 0.8–1.0 cubic foot per min, CFM, of air per pound of resin) is required. For example, if 27 kg/hr (60 lb/hr) of resin are to be molded, dry air capacity of 80–100 m³/hr (48–60 CFM) will be needed.

The air temperature is equally important and is related to the drying time. Air temperature should be measured at the point of entry to the hopper (not at the dryer). Prolonged drying at elevated temperatures can cause the loss of some additives and discoloration of pellets or granules. When extended drying times are required, lowering the temperature is the best practice. When the temperatures required to dry resins are above 105 °C (220 °F) hoppers and air transfer lines should be well insulated to ensure dryer effectiveness and to conserve energy. Dryers that incorporate an after-cooler (which lowers the temperature of return air before it enters the desiccant bed) are preferred because desiccants can remove and hold more moisture at lower temperatures. When drying at temperatures over 120 °C (250 °F), after-coolers are required.

The fourth important variable is the dew point of the air entering the hopper. This must be -20 °C (0 °F) or lower throughout the drying cycle in order to adequately dry the resin.

Vacuum dryers operate by heating the resin in a chamber to a set temperature for that resin, then indexing the chamber to a position where a vacuum is pulled to remove the moisture. The important variables are temperature, vacuum, and time. The temperature depends on the resin and moisture content and the vacuum is a minimum of 6000 Pa (600 mm or 24 in of water column). The typical times for heating and application of the vacuum are 20 minutes.

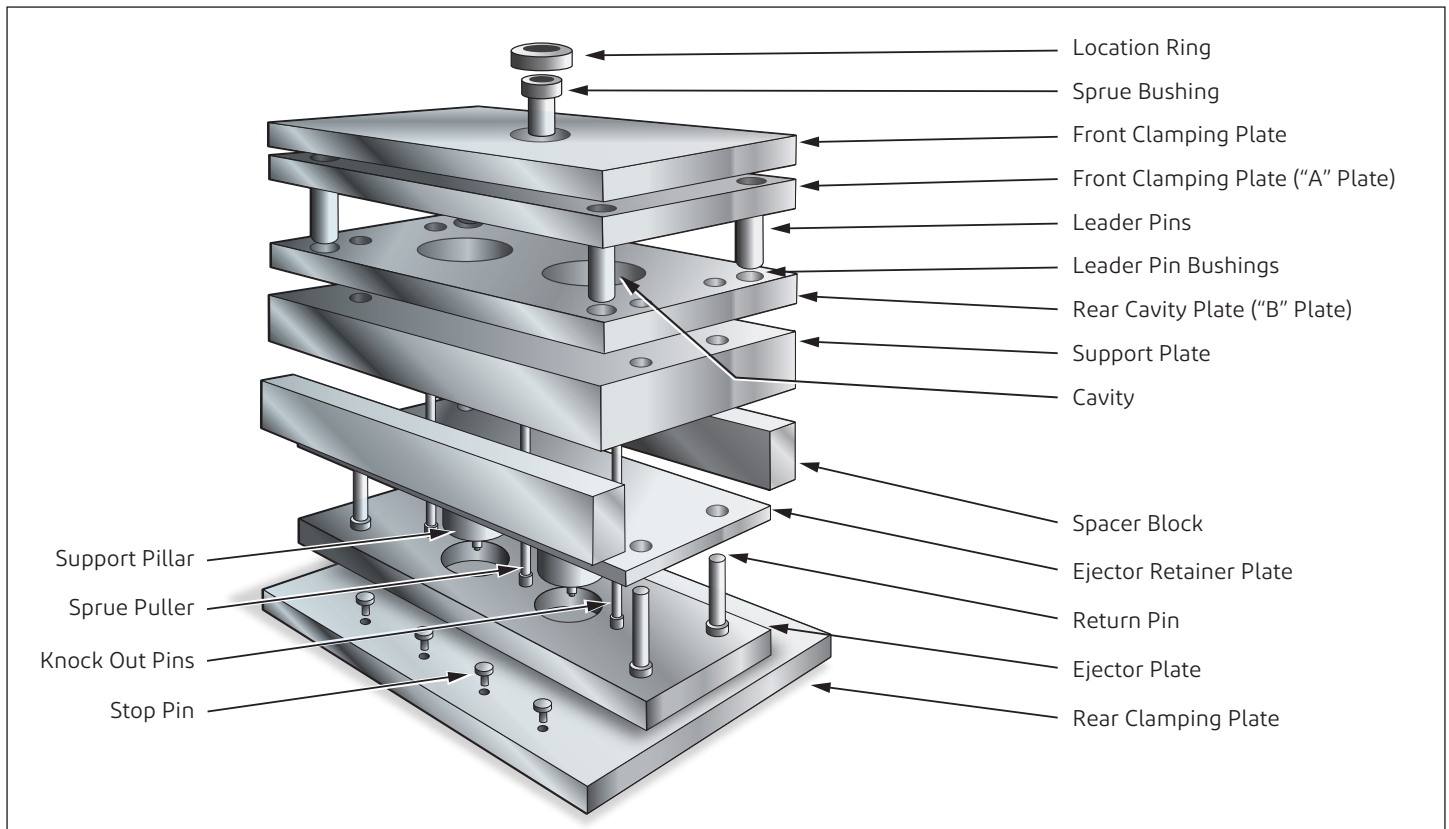
4. MOLDING EQUIPMENT—MOLD

Delrin® acetal resins have been used in many types of molds, and many molders have diverse expertise in mold design for Delrin®. Molds for Delrin® are basically the same as molds for other thermoplastics. The parts of a typical mold are identified in **Figure 4.1**.

This section will focus on the elements of mold design that deserve special consideration for processing Delrin® and can lead to higher productivity and lower cost for the molder. These topics are:

- Mold Temperature Control
- Mechanical Structure
- Conventional Runner System and Gate Layout
- Hot Runner Systems
- Venting
- Draft Angles
- Sharp Corners
- Undercuts
- Ribs
- Weld lines

Figure 4.1 Exploded View of Mold



Mold Temperature Control

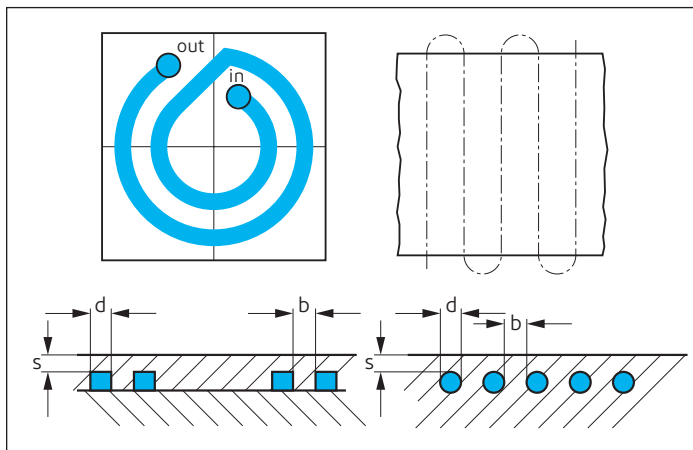
Mold temperature control must be a part of the overall design concept for the mold. Mechanical properties, cycle time, dimensional accuracy, and distortion of the part are all influenced by mold temperature.

In order to achieve a consistent cavity surface temperature, it is essential to have a well-designed regulation circuit in the mold in addition to a temperature controller with suitable pressure, heating and cooling capacity.

Basic Recommendations

- When molding DuPont thermoplastic resins, one must ensure the mold surface temperature is much higher than room temperature. In order to shorten the time needed to heat the mold and to maintain constant temperature, insulating plates should be provided between mold and machine.
- For large molds and temperatures above 100 °C (212 °F), it is recommended to thermally insulate the mold on its outside walls.
- Flat mold areas should be adapted with spiral or drilled cooling channels. Recommended diameters and their approximate distance from the surface of the mold are shown in the Table of **Figure 4.2**. Depending on the size of the part, it may be necessary to provide several separate cooling circuits. The temperature difference between entering and exiting fluid should be as small as possible, ideally <5 °C (<10 °F).

Figure 4.2 Cooling Channel Design Considerations

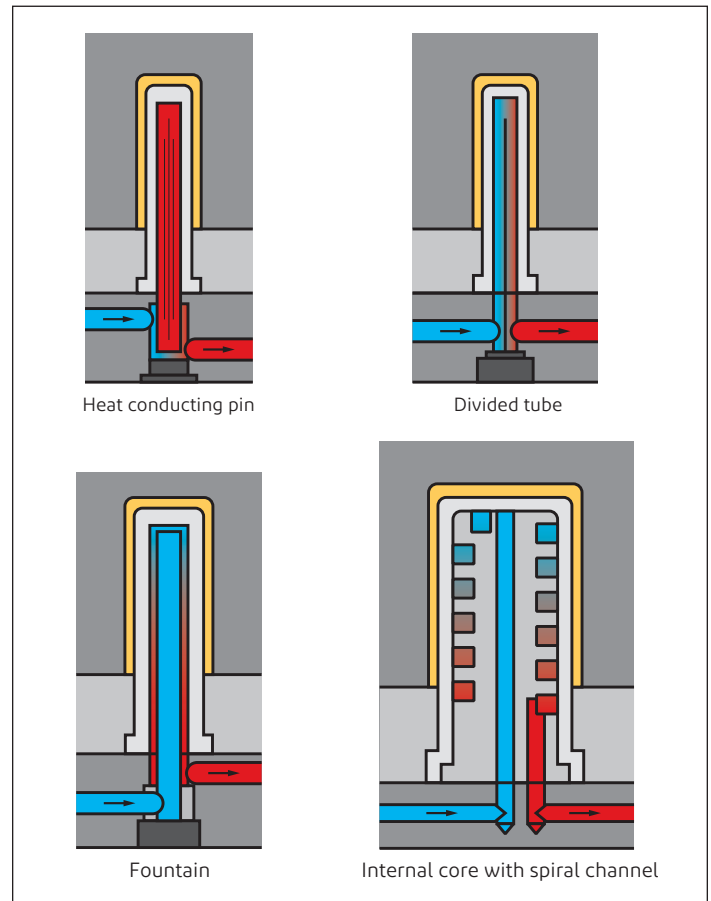


Wall thickness of the molding	Channel diameter or width (d)	Distance (s)	Channel Spacing (b)
< 2 mm (0.08 in)	8 mm (0.32 in)	4 mm (0.16 in)	~ 1d
< 4 mm (0.16 in)	10 mm (0.39 in)	7 mm (0.28 in)	~ 1d
< 6 mm (0.24 in)	12 mm (0.47 in)	9 mm (0.35 in)	~ 1d

- A separate or serial cooling circuit is recommended for multi-cavity tools, because the flow rate can easily be controlled. A parallel configuration may lead to different surface temperatures as choking over time causes different flow rates in the parallel channels.

- It is important to have efficient core cooling in order to obtain the shortest possible cycle time. **Figure 4.3** shows some constructions of cooling cores.
- Separate temperature control should also be provided in slides and core-pulls when possible.

Figure 4.3 Cooling Core Methods



Mechanical Structure

DuPont thermoplastic resins require medium to fast injection speeds. Especially in thin wall applications, the specific injection pressure may exceed 100 MPa (14.5 kpsi). Therefore, a stiff mold construction (see **Figure 4.1**) will have an important contribution to:

- Flash-free molding
- Longer mold lifetime
- Wider processing window (i.e., faster injection speed)

To increase mold stiffness, consider using the following recommendations:

- Thick platens
- Large spacer blocks
- Very stable frame when using many inserts or large hot runner systems
- Support pillars between rear clamping plate and support plate

Conventional Runner System and Gate Layout

Runner (or feed) systems should efficiently convey molten polymer to the part gate in order to allow for the production of parts with a thoughtful balance between the resin pressure drop, the economics of material usage, and the resultant cycle time from runner system sizing. Ideally, the runner system should be naturally balanced and the gate type and placement on the part thoroughly considered. Runner removal, knit-line placement, resin flow length, and gate vestige allowance are all significant considerations for gate type and placement on the part.

The gates of a mold play a major role in the success or failure of a molding job. They are often highly stressed areas of the part and they should not be placed in mechanically critical areas. Particularly with crystalline material, like Delrin®, the location, design, and size of a gate are key factors to allow for a continuous flow to achieve optimum packing during all parts of the packing phase of molding. The following provides further details on these factors.

Runner System

When sizing conventional feed systems, the first point to be considered is the wall thickness (T, refer to **Figure 4.4**) of the molded part. The diameter of the runner should not be less than the wall thickness + 1 mm (0.04 in) of the injection molded part. The runner should not be less than 1.5 mm (0.06 in) even for parts thinner than 0.5 mm (0.02 in). Starting out from the gate, the runner diameter at each branch point may be increased so that an almost constant shear rate is maintained. A simple estimate is shown in **Figure 4.4**.

To prevent the inevitable cold slug from the injection nozzle reaching the molding, the sprue should always be extended so that the cold slug can be intercepted. This extension should have roughly the same diameter as the nozzle to ensure that the cold slug is retained.

Gate Location

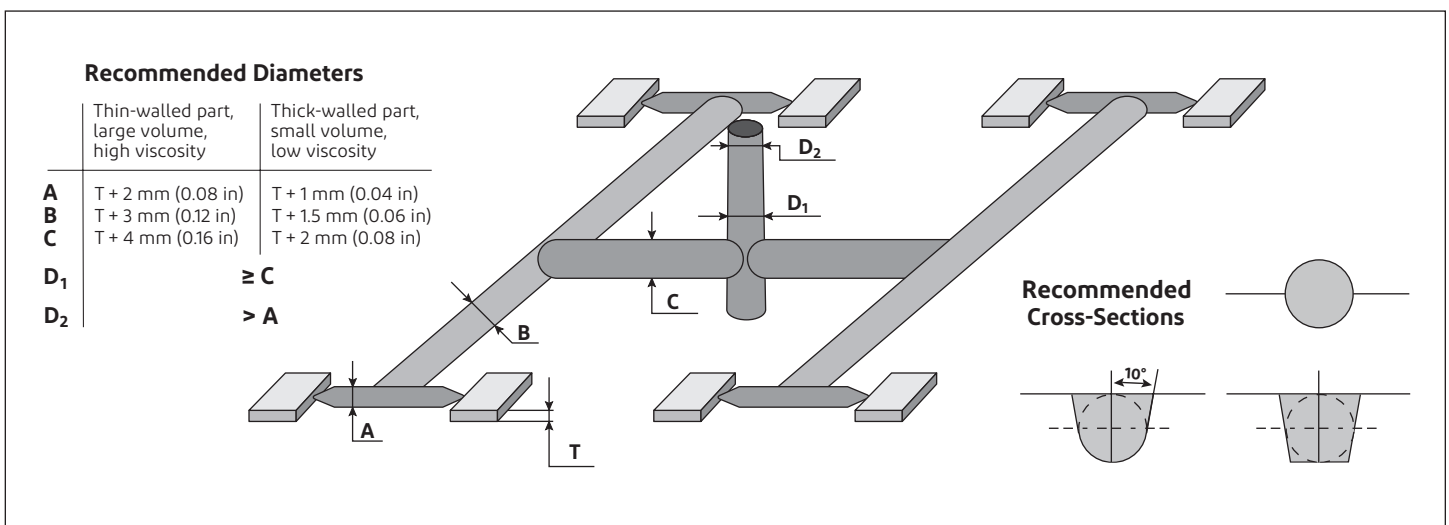
As a key rule, when a part is not uniform in wall thickness, the gate must be located in the thickest section. The respect of this basic principle plays an essential role in obtaining optimum packing and, consequently, the best mechanical properties, dimensional stability, and surface aspect. Careful attention should be paid to avoid every bottleneck (reduced section along the flow of the melt) between the gate and all areas of the part.

An area where impact or bending will occur should not be chosen as the gate location, because the gate area may have residual stress and be weakened since it works as a notch. Similarly, the gate should not cause a weld line to occur in a critical area. The gate should be positioned so that the air will be swept toward a parting line or ejector pin—where conventional vents can be located. For example, a closed-end tube such as a pen cap should be gated at the center of the closed end, so air will be vented at the parting line. An edge gate will cause air trapping at the opposite side near the closed end. When weld lines are un-avoidable, for example around cores, an escape for gases must be provided to avoid serious weakness and visual flaws. Specific recommendations for venting are given later in this section.

Another consideration in choosing a gate location for Delrin® is surface appearance. Gate smear or blush, as well as jetting, are minimized by locating the gate so that the melt entering the cavity impinges against a wall or core pin.

A central gate location is often necessary to control roundness of gears and other critical circular parts. Multiple gates, usually two to four, are commonly used when there is a central hole to avoid a difficult-to-remove diaphragm gate.

Figure 4.4 Simple Runner System Sizing Design

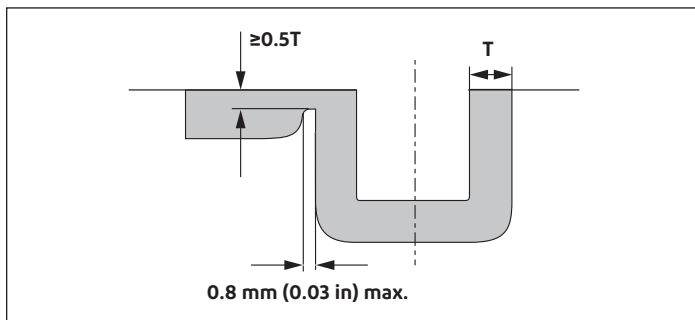


Gate Design

For crystalline materials like Delrin®, the thickness of the gate or its diameter (for a pin-point gate or tunnel gate) determines the freeze-off time, and, therefore, also determines whether it is possible to pack the part (to compensate for the volume reduction due to crystallization) and maintain the pressure during solidification. The gate should remain open until the part density is maximized for a specific material. The thickness (or diameter) of the gate should amount to 50–75% of the wall thickness at the gate. The width of the gate should always be equal or greater than the gate thickness. The length of the gate should be as short as possible and never exceed 0.8 mm (0.03 in). The gate area of the part should not be subjected to bending stresses during actual service. Impact stresses are particularly liable to cause failure in the gate area.

Many gate types have been successfully employed in molding DuPont thermoplastic resins. The location, size and number of gates are also important considerations. Details of a typical edge gate suitable for Delrin® are shown in **Figure 4.5**.

Figure 4.5 Details of a Typical Edge Gate Suitable for Delrin®



Round (pin) gates are preferred for automatic three-plate molds and tunnel-gates (submarine gates) are preferred for automatic two-plate tools because of ease of gate separation and part ejection. See **Figures 4.6** and **4.7**. One must consider carefully the forces required to automatically break gates with the tool's opening for specific resins and part designs. Large gate diameters with very tough resins may present practical limitations on gate sizing.

Figure 4.6 Round (Pin) Gating Design Suitable for Delrin®

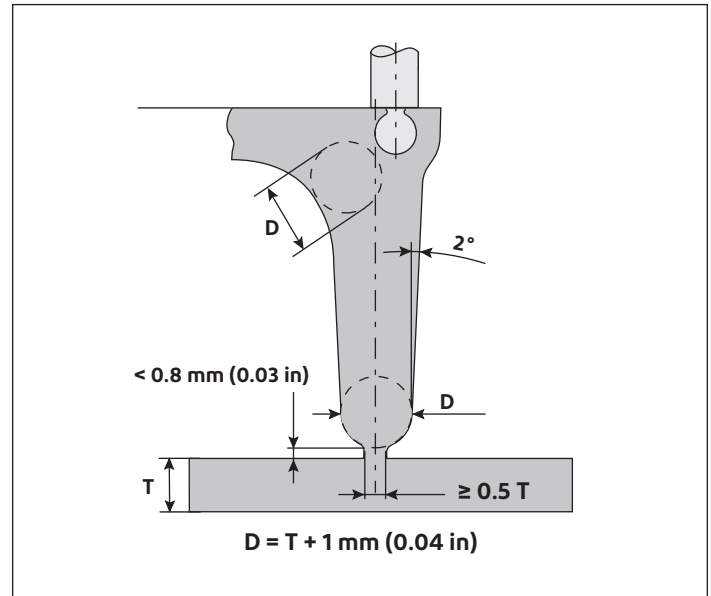
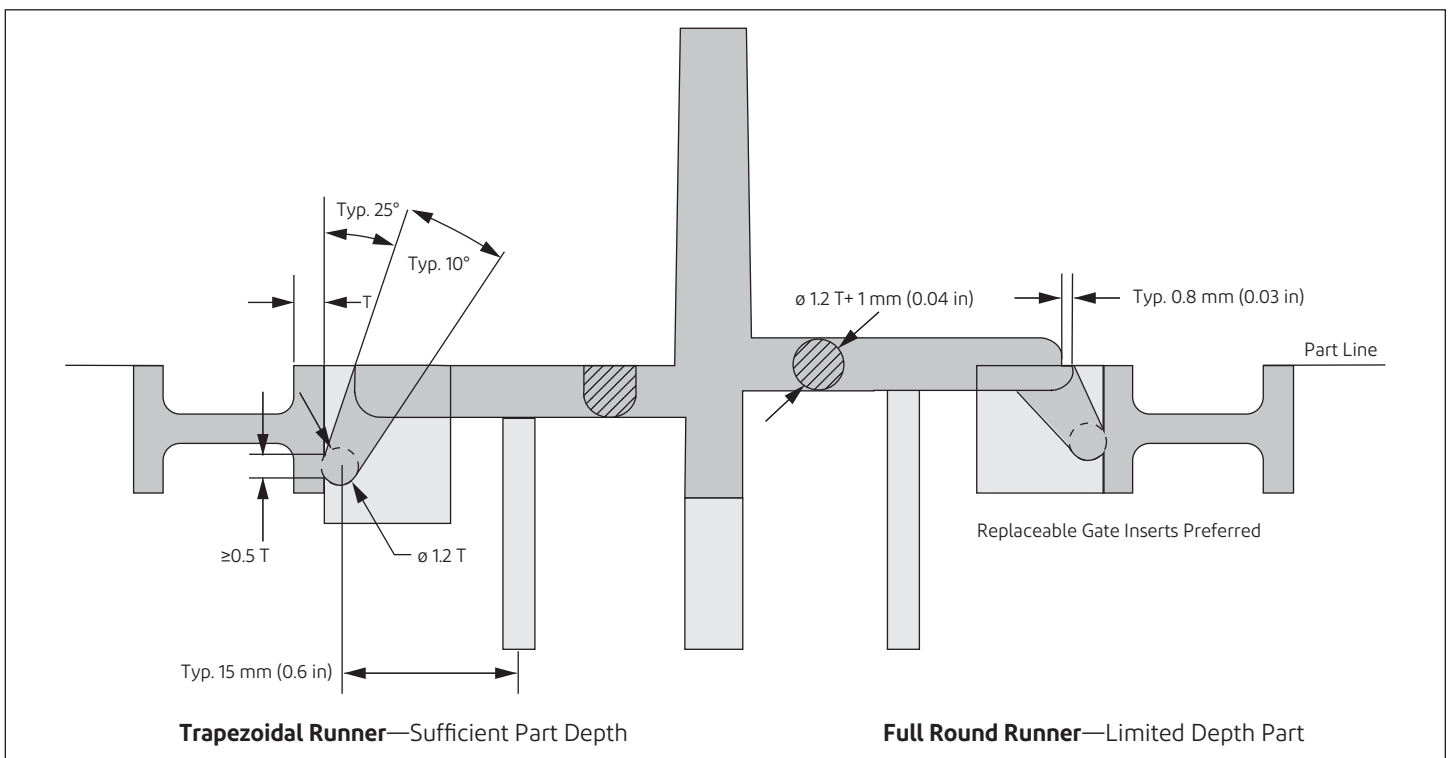
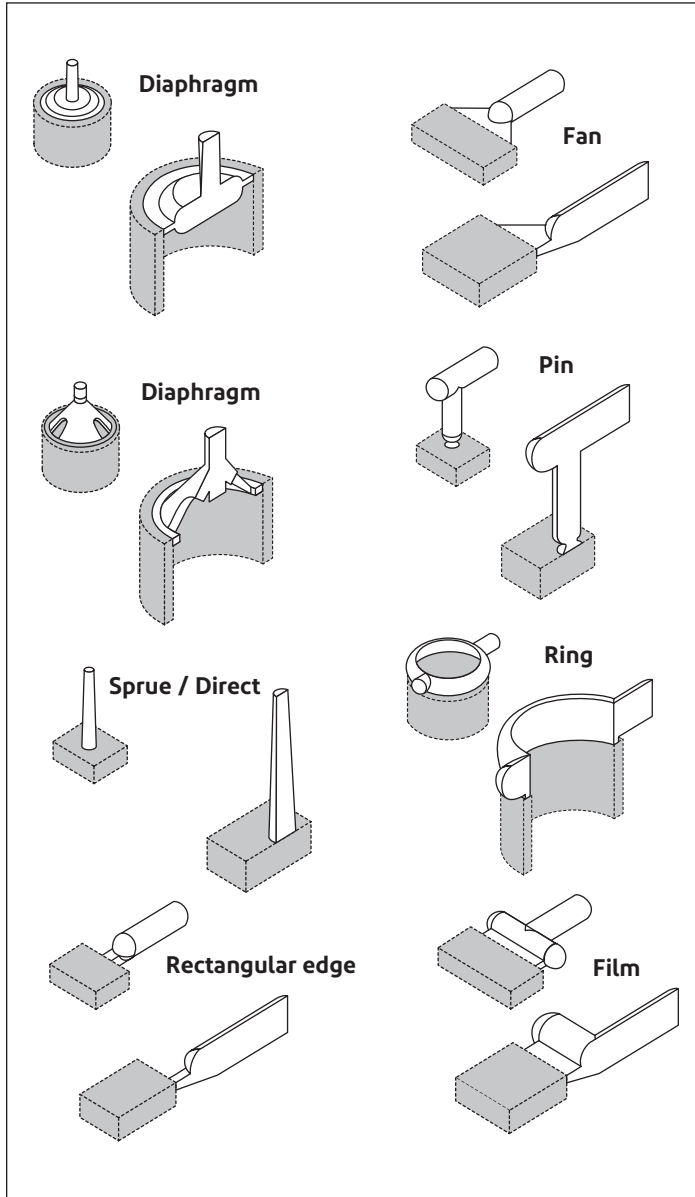


Figure 4.7 Tunnel (Submarine) Gating Design Suitable for Delrin®



In addition to round and rectangular gates, there are many other types of gates such as film, fan, diaphragm, sprue, and ring gates which are illustrated in **Figure 4.8**.

Figure 4.8 Schematic View of the Most Common Types of Gates



To summarize the basic rules:

- Always provide a means of containing the cold slug
- Make the effective runner diameter larger than the molded part wall thickness
- Gate thickness should be at least 50% of the molded part wall thickness

Hot Runner Systems

Selecting the correct hot runner system and its installation may determine how well a mold functions and the ensuing molded part quality. It should be kept in mind that direct gating via hot runner is more difficult with crystalline polymers than with amorphous polymers. The difference comes from the softening or melting behavior of these two types of polymers.

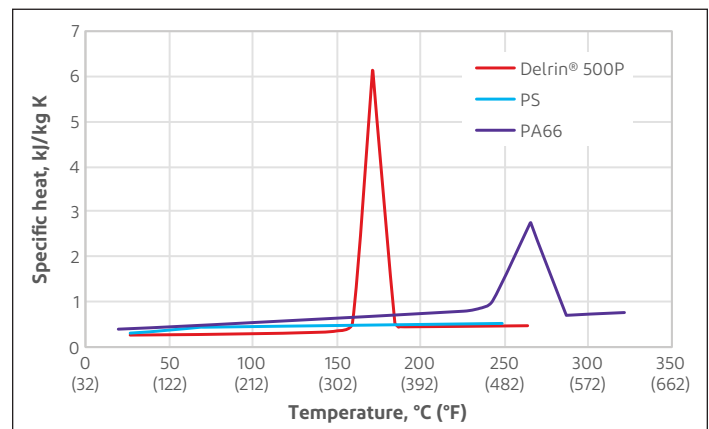
An amorphous material exhibits a gradual softening behavior above its glass transition temperature, T_g , from the solid state to the liquid state, allowing a wide processing window in terms of temperature and viscosity. In fact, as its temperature increases above T_g , an amorphous polymer lends itself first to thermoforming, then to blow molding, and finally to injection molding.

On the contrary, the T_g has usually a limited or negligible effect on the structure of crystalline polymers, which are solid above T_g . At the melt temperature, T_m , crystalline polymers melt sharply and become liquid. As such, Delrin® exhibits sharp thermal transitions due to its inherent crystallinity and hot runner tools are thermally very complex systems. This is exhibited in the sharp increase in specific heat required to heat Delrin® to its melting point in **Figure 4.9**, similar to polyamide 6-6, but in contrast to an amorphous polymer, such as polystyrene.

Such behavior of a crystalline material may involve the risk of:

- Drooling around the gate with consequent problems of bad surface aspect and deformation.
- Plugging of the gates by solidified material, plugs which will be pushed into the cavities, with consequent problems of surface defects and lower mechanical performances. The best way to prevent such problems is to use COLD SUB-RUNNERS.

Figure 4.9 Specific Heat versus Temperature for Delrin® 500P, PA66, and Polystyrene



It is important to consult the hot runner manufacturer in order to get advice on the manifold and nozzle type selection, dependent on the chosen grade. In general, Delrin® “P” grades are preferred due to their better thermal stability during processing.

Some basic rules can be applied when planning a hot runner mold with semi-crystalline thermoplastics:

- The manifold must be naturally balanced. Rheological balancing (i.e., adapting nozzle or sub-runner gate size) can only optimize for either equal-filling time (dynamic balancing) or pack-pressure level (static balancing). Both together are often contradictory.
- Direct gating on the part should be avoided:
 - for small shot weights or long cycle times (total residence time above 10 minutes)
 - for aesthetic parts, as surface defects may occur in the gate area
 - for safety relevant parts, as there is always a cold or inhomogeneous slug coming from the nozzle tip, which might move to a mechanically critical area
 - when no gate vestige or stringing from gate breakage can be accepted.
 - Manifold and nozzles must be perfectly streamlined in order to avoid any hold-up spot. **Figure 4.10** illustrates typical channel geometries.

Figure 4.10 Typical Channel Geometries

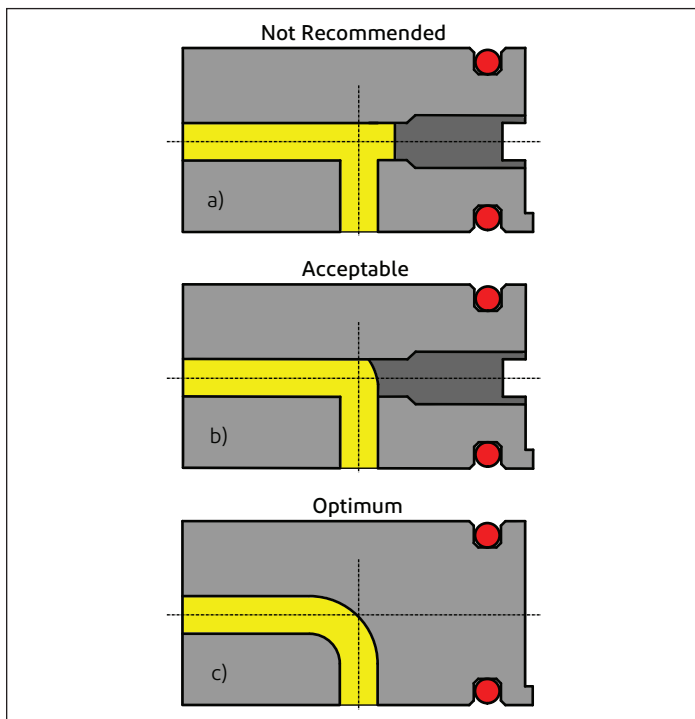
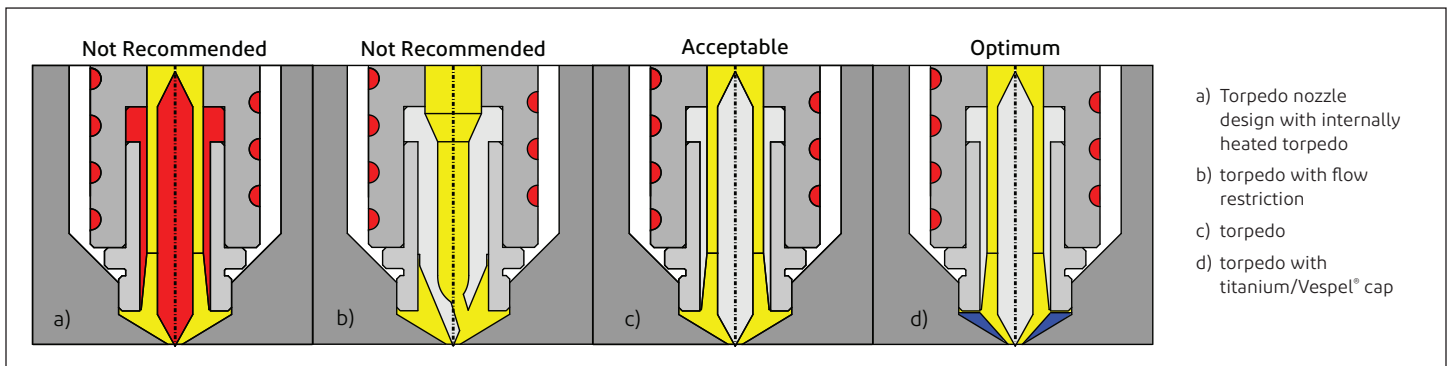


Figure 4.11 Direct Gating Tip Designs



Thermal Control of Hot Runner Molds

Thermal management and streamlining of the flow are very important for hot runner tools. It should be verified that a relatively low temperature setting ($\leq 190\text{ }^{\circ}\text{C}$ [$\leq 374\text{ }^{\circ}\text{F}$]) provides an easy flow of the material with no hold-up spots.

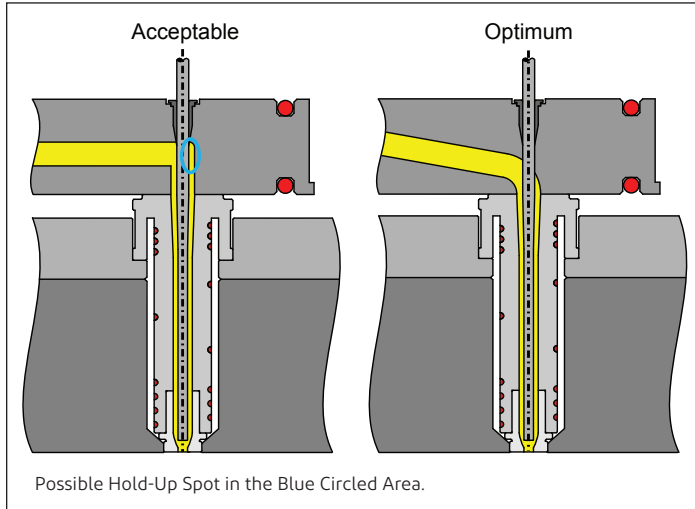
Due to the viscosity of the polymer, its flow is always laminar. This means that the material will remain against the steel wall of the hot runner, and residence time will be very long. For Delrin[®], to avoid thermal degradation with prolonged times, the steel temperature should never exceed $190\text{ }^{\circ}\text{C}$ ($374\text{ }^{\circ}\text{F}$). Degradation can result in splay, odor, black specks, and mold deposit. If the hot runner system solidifies at that temperature and/or degradation signs appear, then it must be modified to improve thermal insulation and heat distribution to remove cold spots. For further information on melt stability, see Chapter 8.

Given the potential for solidification or thermal degradation, thermal balance must be optimal. Temperature differentials of more than $20\text{ }^{\circ}\text{C}$ ($35\text{ }^{\circ}\text{F}$) cannot be tolerated in a hot runner system. As it is difficult to determine the real temperature in a hot runner system, the temperature settings on the controller might need to be set higher as the recommended $190\text{ }^{\circ}\text{C}$ to avoid a freezing of the nozzle. In these cases, special care has to be taken. Externally heated manifolds are preferred over internally heated ones, as they allow better streamlining at intersections and generate less shear in the polymer. For optimal operations, it is essential to have the right combination of hardware (manifold, nozzles, heaters), software (heating control) and set-up (optimum thermal insulation between hot-runner and mold).

“Self-insulating” nozzles should be avoided. This kind of nozzle requires the polymer to flow into a cup-shaped gap between nozzle tip and mold surface, in order to optimize the thermal insulation of the nozzle tip. With Delrin[®], however, the resin in this gap may partially solidify and ultimately thermally degrade. This can create black spots and surface defects at irregular intervals. **Figure 4.11** shows various tip designs for direct gating.

If direct valve gating is needed, it is even more important to have an optimum temperature in the hot runner, as the needle might create additional hold up spots. For thermally sensitive resins, which are critical to hold up time, an adapted manifold design with an improved purging behavior is preferred (see **Figure 4.12**).

Figure 4.12 Valve Gate Designs
Standard Manifold Design (left),
Improved Design with Minimized Stagnation (right)



Specific abrasion-resistant metals or treatments are preferred for reinforced grades, specifically at the nozzle tip, where shear is highest. Hard metal tips have led to much longer life-times of the tip. Nozzle tips should also be exchangeable. This allows for easier control of the effects of abrasion, and may reduce the cost of modifications, if they are necessary.

When heating up a hot runner containing DuPont thermoplastic resin, it is important to first heat the system to approximately 20 °C (35 °F) below the melting point of the resin and then to wait at least 30 minutes at this temperature before heating up to operational temperature. This allows heat to soak in and attainment of a heat balance. Modern controllers allow for such an automated stepwise start-up procedure.

When there is a doubt about hold-up spots in the hot runner, it is advisable to make a color change on the cylinder and then mold continuously for an additional 10 minutes. The system can be shut down and the hot runner and nozzle then disassembled in order to identify the spots which still contain the first color. With the help of the hot runner manufacturer it should be possible to improve the streamlining of the hot runner and nozzle.

With crystalline polymers such as Delrin®, the following is recommended:

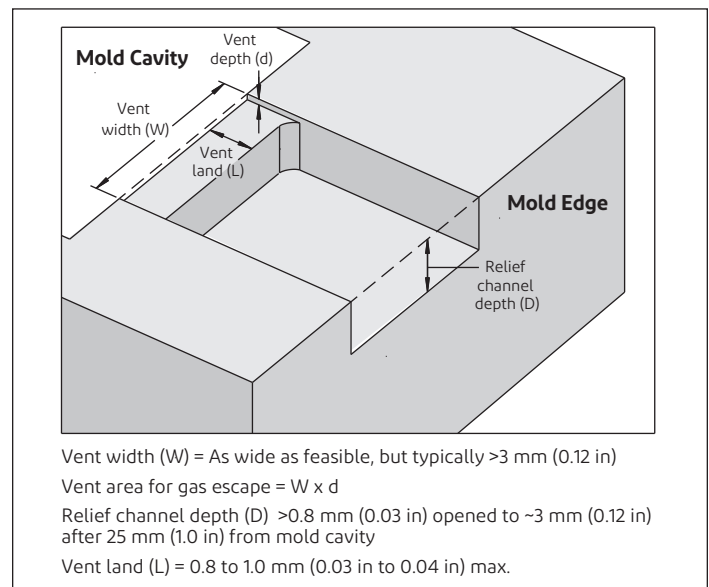
- Use of Delrin® P grades
- A minimum of 25% theoretical cost decrease should be expected before a hot runner is considered
- Highly trained machine operators and mold maintenance toolmakers should be available
- Use of cold sub-runners, never direct gate straight onto the part
- All temperatures in the hot runner system must not exceed 190 °C (374 °F)
- Avoid the use of hot runner molds if surface defects are not acceptable and high part mechanical performance is required
- Avoid the use of hot runners for toughened grades

Venting

Venting a mold for Delrin® is particularly important, and special attention should be given to this factor during both the design of the mold and its initial trial. This attention is required because burning of parts caused by inadequate venting is not easily observed with Delrin®. With other resins, poor venting results in a blackened and burned spot on the part. With Delrin®, however, there may be either no visible flaw or an inconspicuous whitish mark on the molding. Venting problems with Delrin® acetal resins may be made more obvious by spraying the mold with a hydrocarbon or kerosene-based spray just before injection. If venting is poor, the hydrocarbon will cause a black spot where the air is trapped. This technique is particularly useful for detecting poor vents in multi-cavity molds. A convenient source of hydrocarbon spray is a rust preventive spray.

Inadequate venting of molds for Delrin® may cause a gradual buildup of mold deposit where vents should be located and in-mold crevices through which limited venting has taken place. These deposits consist of a white solid material formed from the traces of gas evolved during normal molding. Good vents allow this gas to escape with the air from the cavities.

Figure 4.13 Parting Line Venting



Material	Vent Depth (d) mm (in)	
	Min.	Max.
Rynite® PET	0.012 (0.0005)	0.020 (0.0008)
Crastin® PBT		
Zytel® and Minlon® PA resins		
Zytel® HTN resins		0.030 (0.0012)
Delrin® POM		0.040 (0.0015)
Hytrell® TPC-ET		

Figure 4.14 Cavity and Runner Venting

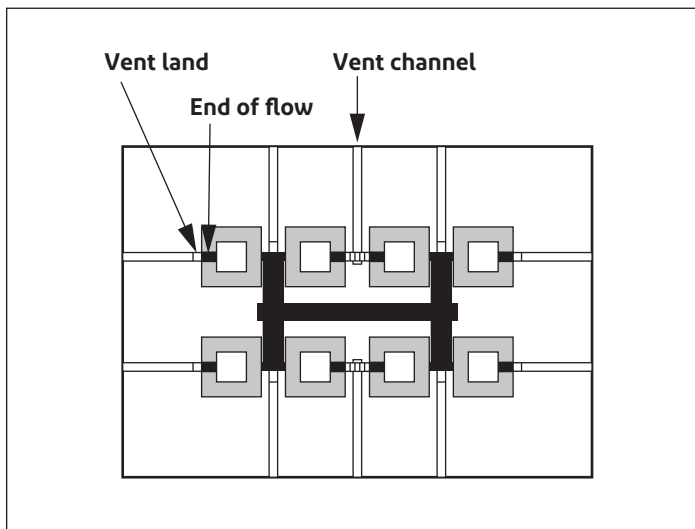
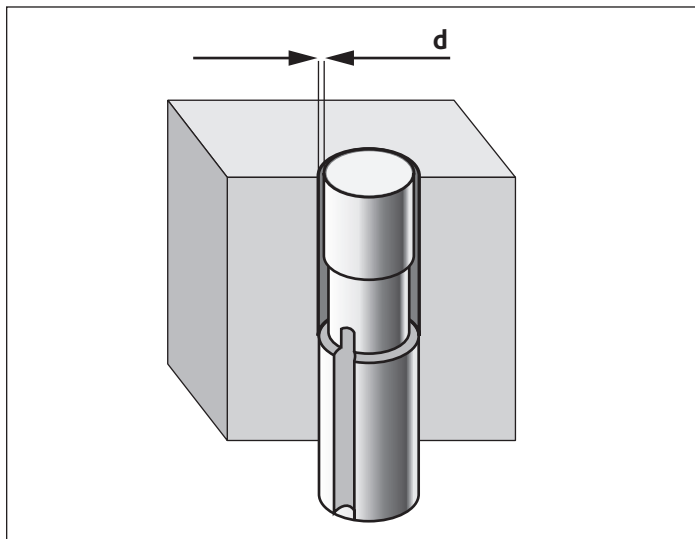


Figure 4.15 Ejector Venting



Both cavities and runners should be vented at the parting line and the ejectors as recommended in **Figures 4.13** through **4.15**. The area of the vent must be large enough ($W * d$) to prevent a rise in gas pressure within the mold cavity. The vent land length (L) should not exceed 1 mm. The area of the escape passage leading from the vent should increase in proportion to its distance from the cavity edge. In the case of low viscosity grades and where there must be a minimum of flash, venting may be conservatively sized (made more shallow) and increased as required.

In summary, inadequate mold venting can cause the following problems:

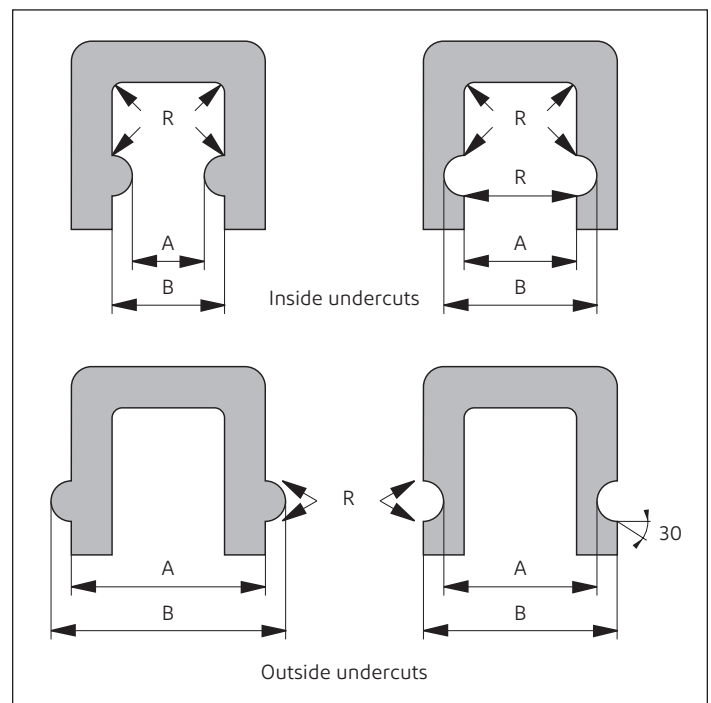
- poor weld line strength
- fast buildup of mold deposit
- erosion or corrosion of the mold
- dimensional variation on the molded part
- surface aesthetic defects like bubbles or blisters
- short shots

Undercuts

General suggestions for stripping undercuts with Delrin® acetal resins are:

- The undercut part must be free to stretch or compress, that is, the wall of the part opposite the undercut must clear the mold or core before ejection is attempted.
- The undercut should be rounded and well-filleted to permit easy slippage of the plastic part over the metal and to minimize stress concentration during the stripping action.
- Adequate contact area should be provided between the knockout and plastic part to prevent penetration of the molded part or collapse of thin wall sections during the stripping action.
- The length of the molding cycle and specifically the Hold (Pressure)Time (HPT) should be optimum to avoid excessive shrinkage with inside undercuts. Sufficient part rigidity must be developed without causing binding due to excessive shrinkage around pins forming an internal undercut. Ejection of parts with undercuts on the outside diameter will be aided by mold shrinkage.
- Higher mold temperature, which keeps the part hotter and more flexible when the mold opens, may aid ejection from an undercut.
- Generally, parts of Delrin® acetal can be molded with a maximum 5% undercut. Calculation of allowable undercut is illustrated in **Figure 4.16**. The allowable undercut varies somewhat with both wall thickness and diameter.

Figure 4.16 Undercut Calculations $(B-A)/B \leq 5\%$



Ribs

Very often, ribbed parts will perform much better in terms of cycle time, mechanical performance, and warpage than very thick, improperly packed parts. It is economically impossible to pack sections greater than 6–8 mm (0.24–0.32 in) thick during all the crystallization time (solidification: see **Figure 7.6** for Part Thickness vs. Hold (pressure) Time). However, an improper rib design could also cause defects such as sink marks.

Recommended rib dimensions are shown in **Figure 4.17**. Note that the radius at the base of the rib should not be too small to preserve part toughness (**Figure 4.18**). For further information about rib design please consult the *General Design Principles for DuPont Engineering Polymers*.

Figure 4.17 Suggested Rib Dimensions Versus Wall Thickness

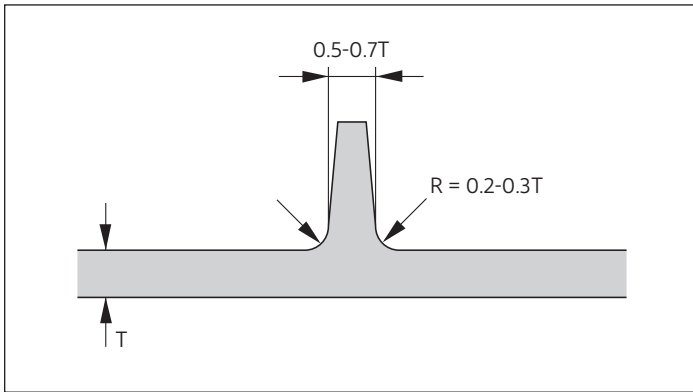
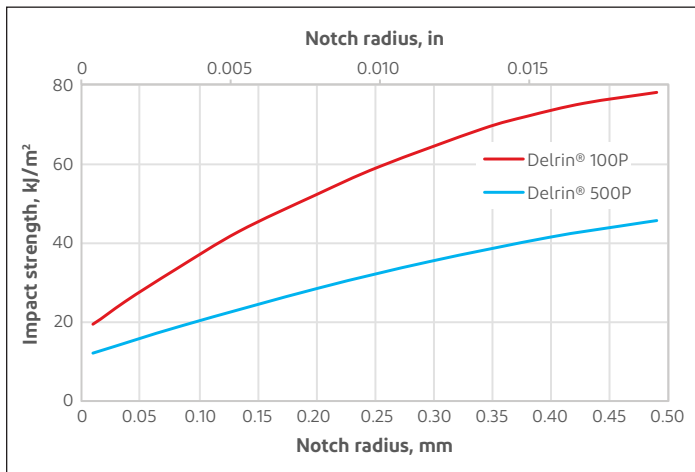


Figure 4.18 Impact Strength as a Function of Molded Notch Radius



Sharp Corners

Part designs and mold finish requirements should adhere to the basic rules of rounding sharp internal corners of a part. Parts from unreinforced resins like most of the Delrin® grades are far more sensitive to the notch effect of sharp corners. The diagram in **Figure 4.18** shows the effect of notch radius on impact resistance of test bars molded from several grades of Delrin®. Note that the notches have been molded (simulation of real life and not machined as required by the standard Izod and notched charpy tests).

From this diagram it can be seen that an increase of an internal radius of curvature from “0” (approximately 0.01 mm [0.004 in], as sharp as can be machined) to 0.25 mm (0.01 in) more than doubles the impact resistance.

Note, also, that sharp corners are not desirable in plastic parts because they are an important contributing factor to warpage.

Draft Angles

Mold surfaces that are perpendicular to the parting line should be tapered to allow easy ejection. These include ribs, bosses, and sides. A taper (draft angle) of 0.5° to 1° per side is usually satisfactory with DuPont thermoplastic resins. Softer, more elastic resins (such as toughened grades) may require slightly higher taper to 2° per side.

Weld Lines

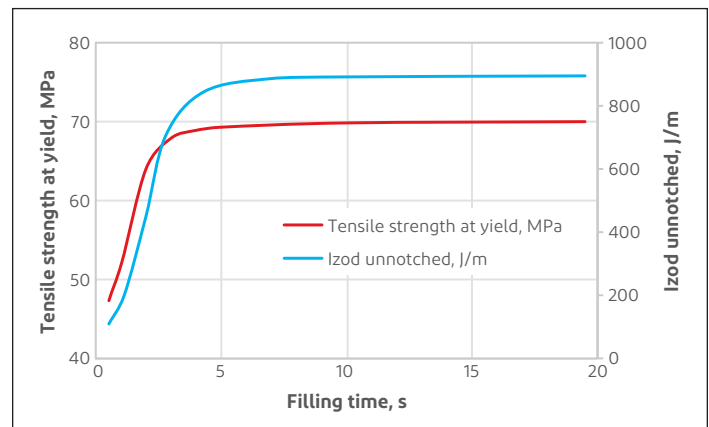
Weld lines occur where two melt flows join together. Weld line position can be defined by short shots, or by flow simulations (if the mold does not exist yet). If the mold is provided with proper venting (see Venting), the weld line strength should be at least 80–90% of the nominal strength value of the resin.

To optimize weld line strength, two parameters are important:

- Optimum Hold (Pressure)Time, to ensure the welding of the flow fronts under pressure (for the correct HPT see Chapter 7)
- Optimum filling rate, which will depend on part thickness (approximately 1 second per 1 mm (0.04 in) of part thickness).

Figure 4.19 shows the weld line strength of a 4 mm (0.16 in) thick test bar in Delrin® 100P gated at both ends. Both tensile strength and toughness are seriously affected if filling time is not optimized.

Figure 4.19 Tensile Strength (Left Scale) and Unnotched Izod Impact (Right Scale) of a Delrin® 100P Test Bar, 4 mm (0.16 in) Thick, Molded at Both Ends with Different Filling Times



Mold Cleaning and Maintenance

As a general rule, molds for processing Delrin® require the same care as those for processing other thermoplastic materials. Wiping the mold and applying a rust-preventing solution is usually adequate after a production run.

Due to the critical nature of the vents, the vent dimensions should be checked during routine maintenance. Vent depth and /or hobbing (deformation of the parting line opposite the vent) should be carefully checked. Vents should be modified if the vent depth is less than 0.01-0.015 mm (0.0004-0.0006 in). Any hobbing that blocks the vents should be ground off.

Depending on the type of deposit the cleaning procedure is as follows:

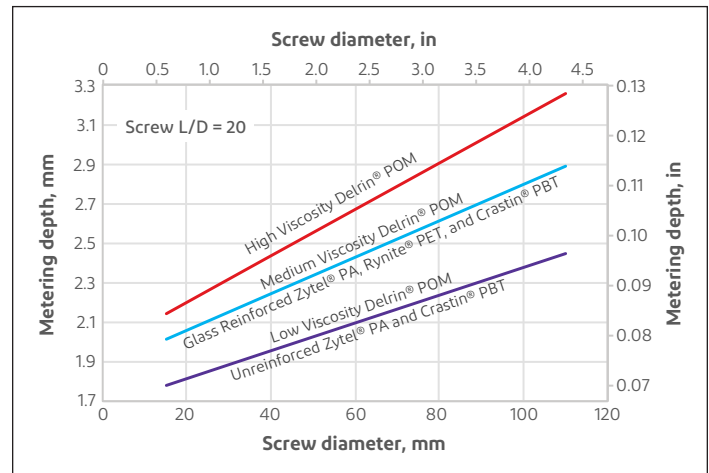
- White deposit (due to the accumulation of paraformaldehyde)—This deposit can be removed with benzyl alcohol or isopropanol. Frequent cleaning of the tool with these solvents during molding will prevent the accumulation of this deposit.
- Translucent or colored deposit—This deposit is normally observed near the gate (in case of overshear of the material), on pins or near hot spots. The use of a less shearing gate (see gate design recommendations) or a more even mold temperature will stop or tremendously decrease the buildup of this deposit. It can be removed with commercial alkaline chemical cleaners. Efficiency of the cleaning agent can be improved with an ultrasonic bath.

5. MOLDING EQUIPMENT—INJECTION UNIT

Screw

DuPont thermoplastic resins can be processed on all commercially available retracting-screw injection molding machines. In order to obtain good homogenization and to ensure proper processing, the L/D ratio of the screws used should not be too small (min. 20). High viscosity Delrin® resins (100 family grades) require deeper metering depths due to the viscous nature of the resin as compared to low viscosity grades (900 family grades), as seen in **Figure 5.1**. Standard three-zone screws with check rings are adequate for thermoplastics.

Figure 5.1 Screw Metering Depth as a Function of Screw Diameter



Screws made from CPM9V hardened steels are recommended for long life and corrosion resistance when used for processing DuPont thermoplastic polymers. Please contact your machine and screw manufacturer for further details and recommendations.

Screw Design

Screw design is a key parameter for productivity, because for crystalline materials the screw rotation time is an inherent part of the cycle time. It should take in consideration the specific melting behavior of the crystalline material, i.e., solid up to the melting point, high demand of heat during melting, and low viscosity of the molten material.

Although general-purpose screws are widely used for molding Delrin®, optimum productivity will require a specific design. Exceeding the output capability of an inadequately designed screw will cause wide temperature variations and unmelted particles (sometimes unmelt and degraded material have been observed at the same time). The result is loss of toughness, variability in shrinkage and dimensions, warping, surface defects, plugged gates (leading to short shots), or other molding problems.

Due to the specifics of the melting process of a crystalline polymer, a screw designed for Delrin® will have shallow flight depths in the metering section and a slightly higher compression than a general-purpose screw. Specific suggestions are given for various screw diameters and composition of Delrin® acetal resin in **Table 5.1**. Compression ratio is the ratio of volume of one turn in the feed section to that in the metering section (can be approximated to the ratio of the depth of the two zones).

The length of the screw will also affect the melt quality (an insulating material needs some time to get the thermal energy transferred even if the shear contributes to the heating process). The preferred length is about 20 times the screw diameter or 20 turns when the pitch and diameter are equal. The screw should be divided as follows: 30–40% (6–8 turns) feed section, 35–45% (7–9 turns) transition and 25% (5 turns) metering section. Screws with 20 turns are commonly divided into 7 turns feed, 8 turns transition and 5 turns metering. In screws less than 16 diameters long, it may be necessary to reduce the pitch to get up to 20 turns. Definitely, the feed section should never be less than 6 turns.

The relatively high compression ratio screws suggested for Delrin® are designed to increase the heat input by mechanical working of the resin. Because the energy for this increase comes from the screw motor, additional horsepower must be available if an increase in melting capability is to be realized.

Screw Size

The ideal screw size is determined by the volume of the current shot. Optimum productivity will be achieved when the shot size requires a screw travel during plasticization equal to or lower than 50% of the capacity of the injection unit. Otherwise, screw rotation speed will have to be decreased at the end of the travel to guarantee an homogeneous melt, leading to a loss in productivity. Practically, optimum productivity is achieved with a screw travel of between 1 and 2 diameters of the screw.

Thermal settings of the injection unit will be dependent on the residence time (HUT) and hence dependent on the cycle time. Rules will be presented under “Molding Process”.

Screw Design for the Use of Color Concentrate

A flow analysis shows that the major part of the flow in the screw is laminar, then divided in the back flow valve (due to the changes in flow direction), and still laminar in the adaptor, nozzle, sprue, etc. To get optimum melt quality, to disperse pigments and color concentrates, it is strongly recommended to add a mixing head. The purpose of a properly designed mixing head is not to mix material by turbulence (turbulent flow is impossible with highly viscous molten polymer), but by forced changes in flow direction.

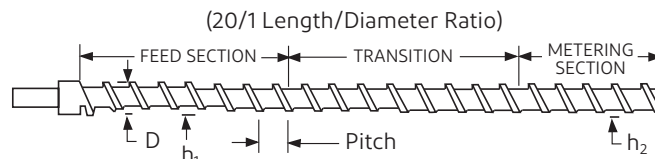
ELCee™ Screw

Another solution to achieve optimum productivity when molding highly crystalline resins such as Delrin®, is to use a special screw designed by DuPont called the “ELCee™ screw.” The ELCee™ screw is designed to capitalize on the rheological characteristics of resins with better control of shear on the melt, making the screw more efficient. This allows the molder to run the molding machines at faster cycles and produce parts of higher quality. (Consult your local DuPont representative for more information.)

Check Ring or Back Flow Valve

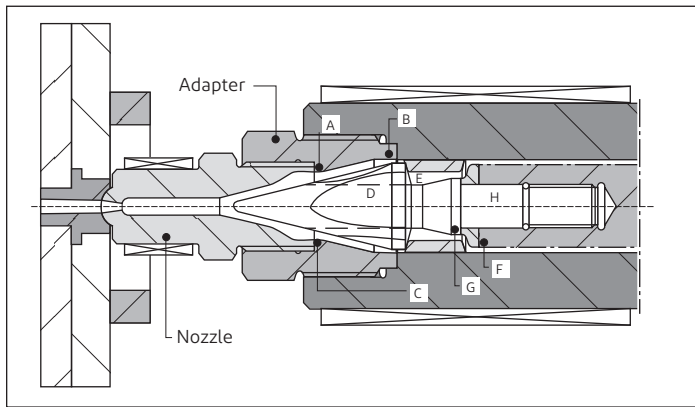
The check ring shown in **Figure 5.2** prevents melt from flowing backward during injection. This unit must be properly designed for stream-lined flow, minimized flow restrictions and elimination of resin hold-up. A malfunctioning check ring that allows resin backflow may be caused by poor design or maintenance. A leaking check ring will cause poor control of packing and dimensional tolerances and may contribute to variable screw retraction time, which can increase cycle.

Table 5.1. Screw Design for Delrin® Acetal Resins



Nominal diameter (D)	Medium and Low Viscosity Grades: Delrin® 500P, 900P, 500T		High Viscosity Grades: Delrin® 100P, 100ST	
	Depth of feed section (h ₁)	Depth of metering section (h ₂)	Depth of feed section (h ₁)	Depth of metering section (h ₂)
mm (in)	mm (in)	mm (in)	mm (in)	mm (in)
30 (1-1/2)	5.4 (0.240)	2.0 (0.087)	5.2 (0.230)	2.6 (0.105)
45 (2)	6.8 (0.290)	2.4 (0.100)	6.5 (0.270)	2.8 (0.115)
60 (2-1/2)	8.1 (0.330)	2.8 (0.110)	7.5 (0.300)	3.0 (0.120)
90 (3-1/2)	10.8 (0.420)	3.5 (0.140)	8.7 (0.340)	3.6 (0.140)
120 (4-1/2)	13.5 (0.510)	4.2 (0.160)		

Figure 5.2 Design of Adaptor and Check Ring



A satisfactory check ring must meet the following requirements:

- No hold-up spots
- No flow restrictions
- Good seal
- Control of wear

These requirements are provided in the check ring design shown in **Figure 5.2**.

The slots or flutes (D) in the screw tip are generously proportioned, and the space (E) between the floating ring and tip is sufficient for resin flow.

The seating of the fixed ring is cylindrical where it joins both the end of the screw (F) and the screw tip (G) to permit accurate matching of these diameters and avoid hold-up.

The screw tip thread has a cylindrical section (H) ahead of the threads that fits closely in a matching counter-bore for support and alignment of the screw tip and check ring seat.

The screw tip and check ring seat should be harder (about Rc 52) than the floating ring (Rc 44), because it is less expensive to replace the floating ring when wear occurs.

Wear resistant steel is suggested for the tip. Good matching of cylindrical diameters is essential to avoid hold-up spots.

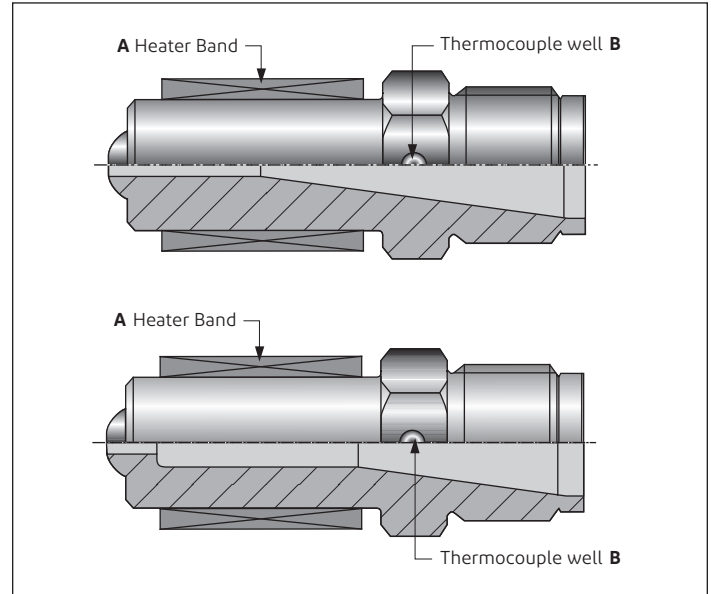
Screw Corrosion/Abrasion

Glass-reinforced resins, can cause wear in certain areas of the barrel, screw, and mold. When molding large quantities of these resins, certain precautions should be taken to minimize wear effects in the equipment and molds. To improve the injection unit when processing glass reinforced resins, hard surfacing alloys, and/or high loaded steels should be used for barrels, screws, and check ring. Tests on bi-metallic specially treated injection units (barrel, screw, and check ring) show a lifetime improvement of 5 to 10 times compared to standard equipment. In order to minimize screw wear, special abrasion, and corrosion resistant steels and treatments are available. Contact your machine and screw manufacturer for further details and recommendations.

Nozzles

DuPont thermoplastic resins can be processed with open nozzles, see **Figure 5.3**. However, decompression of the melt may be carried out after the end of plasticizing to minimize drool. As with other semi-crystalline polymers, Delrin® may drool from the nozzle between shots if the nozzle is too hot, or it may freeze if too much heat is lost to the sprue bushing.

Figure 5.3 Recommended Open Nozzles



Long, unheated nozzles are unsuitable, as the melt can freeze very rapidly if the tip of the nozzle touches the cold tool. If extended nozzles are used, uniform temperature control must be maintained over the whole nozzle length in order to prevent overheating and cold spots.

It is important to maintain nozzle temperature uniformity. This may be accomplished by using a thermal insulating pad between the nozzle and the tool or may be accomplished by withdrawing the nozzle from the tool after completion of the metering operation (sprue break). Utilizing sprue break, should not be attempted with hot-sprue or hot-runner tooling. If the nozzle is not insulated from the tool it cools rapidly and consequently the temperature of the nozzle must be increased to prevent freezing. That may lead to thermal degradation of the melt. Nozzle diameters should not be too small in order to prevent premature freezing.

Self-closing nozzles, particularly those with complicated flow channels, should not be used. With certain needle-type self-closing nozzles, problems due to wear and blocking of the needle can occur when glass fiber reinforced materials are processed. Special attention should be applied to insuring streamlined flow paths which eliminate all potential for hold-up spots.

If self-closing nozzles are used for processing thermoplastics containing glass fibers, the cylinder and nozzle should be purged with an unreinforced material (e.g. PE) before shutting down the machine. This minimizes deposits from glass fibers on the seal surface when the machine is reheated. Although shutoff nozzles have occasionally been used successfully with Delrin®, they tend to cause holdup of resin that results in brown streaks or gassing, especially after some wear has occurred in the moving parts of the nozzle. These nozzles are not generally recommended for Delrin® on safety grounds alone.

The nozzle should always be equipped with an independent temperature controller because a simple power control is often too inaccurate to guarantee precise temperature regulation.

Accumulator for Thin Wall Applications

Glass-reinforced and, especially, thermally conductive grades generally require fast injection speeds. Machines equipped with an accumulator may allow for fast injection speeds and help to increase flow length in applications with thin walls.

6. MOLDING PARAMETERS—START-UP AND SHUTDOWN PROCEDURES

General Information on Purging and Start-up

Purging

Purging is essential before and after molding DuPont thermoplastic resins to prevent contamination. Contamination by another resin may occur by the degradation of that resin if it is processed at a much lower temperature. Unmelt contamination may occur by resins that process at a higher temperature. If incompatible resins are mixed, a reaction may occur that degrades both resins. In severe cases, gases may form that cause the resins to be forced out of the nozzle or feed throat at high speeds. This can happen by having even a trace of polyvinyl chloride (PVC) in the system before using Delrin®. Contamination of Delrin® with such material can cause objectionable odor or even a violent blowback.

The best purging materials are resins that are thermally stable under a broad range of temperatures and do not react with other polymers. Good purging resins are polystyrene, cast acrylic (the nozzle must be removed during purging) and high density polyethylene (or glass-reinforced polyethylene, followed by high density polyethylene). Commercial purging compounds may also be used, but it is best to follow them with a “standard” purging resin.

The following purge procedure is recommended for standard injection molding equipment:

- A. Retract screw injection unit from the mold sprue bushing and keep the screw in the forward position.
- B. Run the screw at high RPM and pump out as much of the current (first) material as possible. Add and extrude purge (second) material until it comes out clean. Cylinder temperatures may have to be adjusted, depending on the purge (second) material used.
- C. It is good practice to “shoot” several air shots at a fast injection rate to scrub walls of cylinder before switching to another resin. Care should be employed to avoid possible splatter of molten resin when this is done.

The following purge procedure is recommended for hot runner systems:

- A. Shield personnel from mold.
- B. Raise manifold temperatures 30 °C (60 °F) above first resin’s melt temperature or 10 °C (20 °F) above second resin’s melt temperature, whichever is lower. The temperature used should not be high enough to degrade the second resin.
- C. Extrude the second resin (dried if needed) through an open mold using elevated machine back pressure, until the extruded material no longer contains the first resin in the manifold and the second resin melt looks uniform.
- D. Drop manifold temperature to operating conditions while continuing to extrude the second resin in order to allow it to reach its operating processing temperature.
- E. Adjust the back pressure to normal level.

Start-up

Always consult the machine manufacturer’s recommendations for start-up. The following procedure can be used to supplement the machine manufacturer’s guidelines.

- A. Start with a clean or well purged machine and a closed feed hopper inlet.
- B. Set the cylinder temperature to 30 °C (60 °F) below the minimum recommended melt temperature and set the nozzle at the operating temperature. Allow heat to “soak in” for at least 20 minutes. Raise cylinder temperature to the operating levels.
- C. Confirm the nozzle is at the correct temperature.
- D. Jog the screw. If the screw will not rotate, allow a longer soak time for cylinder temperature. If the screw does not rotate after a longer soak time, a higher melting resin may not have been completely purged from the barrel. Determine the previous resin used and see purging section for guidance.

- E. When the screw begins to rotate, open the hopper's feed inlet briefly, allowing some resin to cover the screw and then close it. Rotate the screw while checking the torque on the screw drive. If the torque is excessive, increase rear zone temperature settings. The nozzle must be open at this time.
- F. Open the hopper's feed inlet and keep the screw in forward position. Start screw rotation and increase the front zone temperature if unmelted particles are seen.
- G. Adjust the stroke to the approximate shot weight and run a few minutes at the approximate overall cycle. The melt temperature should now be checked with a needle probe pyrometer. Make any adjustments in the cylinder temperatures necessary to obtain the recommended melt temperature. (This procedure should be repeated when a significant cycle change occurs.)
- H. Bring injection cylinder forward. Start with a transfer position that will create a short shot and no pack pressure (except where short shots will interfere with safe part ejection). Establish the proper transfer position for the injection rate and then adjust the molding variables for the best part appearance and maximum part weight.

Start-up and Shutdown Procedures for Specific Situations

Start-up with Resin Change

The suggested start-up procedure with Delrin® is designed to prevent overheating of the resin and contamination in the injection unit with material from previous runs.

To start up a machine which contains another resin, the injection unit must be purged with crystal polystyrene until the cylinder and other high temperature zones have been cleared. This can normally be done with cylinder temperatures in the range 210–250 °C (410–482 °F), if appropriate for the previous material. The nozzle is quite difficult to clean by purging, because the laminar flow in this area leads to a layer of polymer sticking to the metal (this is also true for hot runners). It is therefore recommended to switch off the nozzle heater, remove the nozzle, clean it to remove all traces of previous polymer, and reassemble it. The cylinder temperatures should then be adjusted to about 215 °C (419 °F), and the nozzle temperature to 190 °C (374 °F). When both cylinder and nozzle have reached the expected temperatures, Delrin® can be added to the hopper.

In unusual circumstances, an intermediate purge with a harsher compound may be required to remove adherent deposits from the screw and cylinder. Special purge compounds are used for this purpose.

These purge compounds must also be removed from the cylinder by purging with polyethylene or polystyrene before Delrin® is introduced. In the worst cases, e.g., after use of glass-reinforced resins or severe degradation of previous material, it may be necessary to pull the screw and clean the equipment manually to prevent contamination of moldings. Safety point: Polystyrene is chemically compatible with Delrin®, whereas even a trace of PVC is not.

Start-Up From a Cylinder Containing Delrin®

After a safe shut-down procedure, the screw and the cylinder should be essentially empty. To restart, the nozzle and cylinder temperatures should be set at 190 °C (374 °F) to preheat the cylinder and the resin it contains. When the cylinder has reached the set temperature, ensure that the nozzle is open and increase the cylinder settings to normal operating temperatures. When all temperatures are in the operating range, the hopper can be filled and molding can begin after a brief purge with Delrin®.

Start-up after Emergency Shutdown

A different procedure should be used after an emergency shutdown due to loss of power or other causes. In this case, the screw may be full of Delrin® that cooled slowly and was exposed to melt temperatures for a prolonged period. The screw may even be in the retracted position with a large quantity of Delrin® in front of the screw. In order to vent gases from resin that may be degraded, it is essential that the nozzle be open and heated to the operating temperature and Delrin® in this area be completely melted before the cylinder reaches melt temperature. The cylinder zones should be heated to an intermediate temperature below the melting point of Delrin® and the machine allowed to equilibrate at that temperature. Cylinder temperatures of 150–175 °C (300–350 °F) are suggested. After all zones have been at this temperature for 30 minutes, cylinder temperatures should be raised to 195 °C (380 °F). As soon as the Delrin® has melted, it should be purged from the cylinder with fresh Delrin®. The partly degraded, hot purge resin should be placed in a pail of water if it emits an odor. When the old resin is purged from the cylinder, the cylinder temperatures may be raised to normal production settings.

Shutdown

The machine should be purged thoroughly (see Purging) which cuts the time required for subsequent start-up and reduces risk of contamination. The following shutdown procedure is suggested:

- A. Shut the hopper's feed inlet while continuing to mold on cycle.
- B. Empty the barrel and add a sufficient quantity of the appropriate purge resin such as polystyrene or polyethylene and extrude until the purge is clean. Run the screw until the screw pumps itself dry.
- C. Leave screw in forward position.
- D. Shut down power supply.

Shutdown When a Restart with Delrin® is Planned

Shut off the hopper feed and continue molding until the cylinder is empty. For large machines (with a screw diameter above 40 mm [1.57 in]) it is recommended to purge the cylinder with crystal polystyrene, move the screw fully forward, then switch off the heater bands. For small machines move the screw fully forward and switch off the heater bands.

Shutdown When a Restart with Another Resin is Planned

Shut off the hopper feed and continue molding until the cylinder is empty. Purge with crystal polystyrene, leave the screw fully forward, and then switch off the heater bands.

Interruptions

A molding machine with Delrin® in the cylinder at molding temperatures should not be allowed to stay idle. The maximum recommended cylinder residence time, under normal molding conditions, is 10 min for pigmented material and 20 min for natural standard material. In excess of these times, resin decomposition may occur.

If, during the temporary interruption, the cylinder residence time reaches the above limits, close the hopper feed, empty the cylinder and leave the screw forward. The cylinder temperatures should be reduced to about 150 °C (302 °F). At these temperatures Delrin® will be stable even for a weekend shutdown.

Action to Follow When the Nozzle Heater Band Breaks Down

Retract the injection unit, close the hopper and slide it out of the way. If the nozzle is still open, follow normal shutdown procedures. If the nozzle is frozen, heat the nozzle with a gas torch to melt the frozen material inside the nozzle and then purge.

7. MOLDING PARAMETERS

Clamping Force

The clamping force is the force required to keep the mold closed during filling and hold (pressure) time. This force is calculated by multiplying the projected area of the cavity (cavities), including runner system, by the maximum internal pressure (the hold pressure).

Commonly, molds are set using the maximum clamping force of the molding machine. However in many cases, the machine used has a much higher clamping force than actually needed. In these conditions, it is recommended to lower the clamping to the force actually needed by the mold (see the following calculation). This will prevent excessive pressure at the parting line (compression of the vents, hobbing of the parting line, and deformation of the mold components), leading to longer lifetime of the mold and less costly mold maintenance.

Estimating the maximum internal pressure can be done by carrying out a flow analysis. However, for parts with a flow length to thickness ratio less than 100 to 1, normally the internal pressure is equal to the hold pressure.

The following guidelines can be used:

1. For parts needing optimum mechanical properties, the specific clamping pressure must be 1 ton/cm² for Delrin® 50 or 100 families, and 0.85 ton/cm² for other Delrin® flow families.

Example calculation:

- Projected area of part (or parts), including runner system = 115 cm²
 - Material = Delrin® 500P
 - Machine clamping force required = 115 × 0.85 = 98 ton
2. For parts not requiring optimum mechanical properties, it may be possible to mold acceptable parts with lower specific hold pressures (and lower clamping forces).

Melt and Cylinder Temperature

The melt temperature is taken directly from the molten polymer (using a needle pyrometer) and should be checked periodically during a molding run to ensure that it does not exceed the recommended limits.

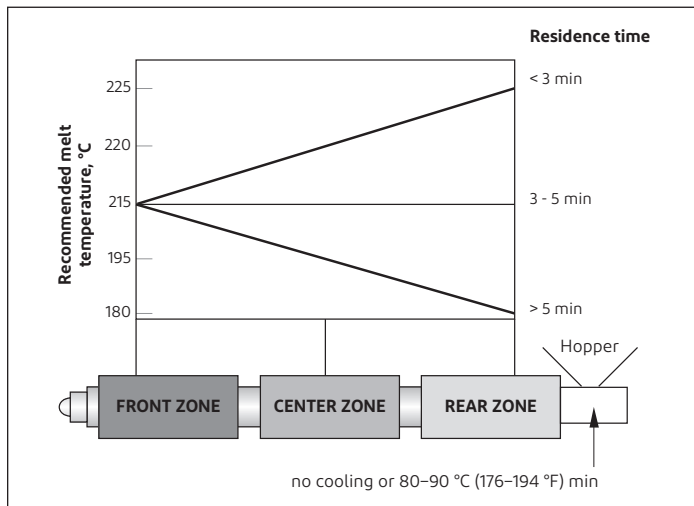
The recommended melt temperature for standard grades of Delrin® is 215±5 °C (419±10 °F). Detailed information on the recommended melt temperature of specific grades of Delrin® for injection molding is available on www.delrin.dupont.com.

In order to take into account the sensitivity of the melt to overheating, processing temperatures must be matched to residence times. The longer the residence time of the melt in the cylinder, because of low shot weight or long cycle times (e.g. due to insert placing), the lower should be the cylinder temperatures. Care should be taken when selecting the machine size or the screw diameter so that the resulting shot weight is not too low.

Generally, for molding semi-crystalline thermoplastic resins, the cylinder temperature profile should be relatively flat. It should be avoided to set any cylinder temperature zone below the melting point of the polymer. The main parameter influencing the temperature profile of the cylinder is the residence time (or Hold-Up Time—HUT) of the polymer in the plastification unit (see *Thermal Stability During Processing*, for HUT calculation).

With a short HUT (<3 minutes, short cycle time, high melt output), higher than normal cylinder settings may be required. With a long HUT (>5 minutes, long cycle time, low melt output), lower settings, especially in the rear zone, may be used. Since generalization of cylinder temperature settings is difficult, it is often wise to begin with a level profile and adjust as needed. The diagram shown in **Figure 7.1** can be used as a guideline for initial temperature settings.

Figure 7.1 Cylinder Temperatures Profile Versus Residence Time for a Given Recommended Melt Temperature (Recommended Nozzle Temperature is 190 °C [374 °F] for All Grades of Delrin®)



Notes:

1. As the preferred melt temperature for toughened grades of Delrin® is about 10 °C (18 °F) lower, the zone settings should be 10 °C (18 °F) lower than shown in **Figure 7.1**.
2. Hopper cooling is not needed and should not be used for Delrin®. As described in Chapter 3, excessive hopper cooling may create problems of screw deposit and black specks.
3. With very small injection units and/or short residence time (HUT), pre-heating the granules (e.g., with a heated hopper) may help to achieve a homogeneous melt.

Nozzle Temperature

The nozzle temperature is adjusted to control drool and freezing (see Nozzles), but it should never be set above 190 °C (374 °F) in order to prevent polymer degradation (the laminar flow and high viscosity of the molten polymer result in very long contact time with the metal wall). If the nozzle freezes with a setting of 190 °C (374 °F), its insulation from the sprue bushing should be improved, or it's inside diameter should be increased if feasible.

Notes:

1. Practically, it is always easier to set the nozzle temperature correctly by using sprue break. The injection unit is pulled back after screw rotation and then the nozzle is insulated from the cold mold. This allows the calories to flow to the tip of the nozzle without having to set too high a temperature, and reduces the risk of stringing from the nozzle.
2. **Hot runner.** By analogy, a hot runner system is a nozzle transferring the molten resin from the injection unit to the part. The principles and recommendations for nozzles are also valid for hot runners. In particular, the laminar flow and high viscosity of the molten polymer again result in very long contact times with the metal wall; so the temperature of the metal in the hot runner should never exceed 190 °C (374 °F), in order to prevent degradation of the polymer.

Mold Temperature

The best mold temperature for long term part performance would be just below the crystallization temperature of Delrin®, e.g., 155 °C (311 °F). This temperature would allow the polymer to crystallize in an optimum state and eliminate any risk of re-crystallization (post molding shrinkage). Obviously it is economically impossible to set the mold at that temperature as the crystallization time becomes almost infinite along with the cycle time.

Practically, a lower mold temperature is used, leading to shorter crystallization time (HPT), therefore, a shorter cycle time, lower mold shrinkage, but higher post mold shrinkage (especially if parts are then exposed to elevated temperatures). A compromise should be found depending on the temperature in use and the required dimensional precision of the molded part short and long term.

For standard Delrin®, a mold temperature of 80–100 °C (176–212 °F) is a good compromise for normal use, giving relatively short crystallization time, high shrinkage but low post mold shrinkage (see Dimensional Considerations). A higher mold temperature will lead to higher mold shrinkage, longer cycle time but lower post mold shrinkage. It is specially recommended for high precision parts used at high temperature. A lower mold temperature leads to shorter cycle time, lower mold shrinkage but much higher post mold shrinkage leading to stresses and distortion.

For toughened Delrin® resins the use of a lower mold temperature (50±10 °C [122±18 °F]) is acceptable without endangering long term part performances.

Note 1: “Mold temperature” is always the term used but the important parameter is the surface cavity temperature. With fast cycling operations, it may be necessary to use a lower mold coolant temperature to maintain the mold surface temperature in the recommended range. Chilled water is often used for very short cycles or to cool core pins and other mold sections that tend to run very hot.

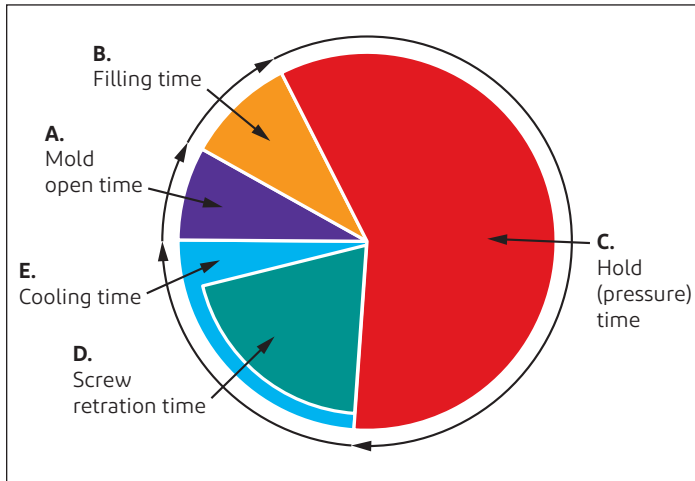
Note 2: Coolant: Closed cooling circuits are the most common types used today. Coolants for closed circuits need to resist heat, freezing, pressure and vacuum. They should neither leave deposits in the circuit, nor corrode the cooling channels and tubes (tubes can be in steel, copper, plastic, rubber etc.). By analogy, the situation is similar to automotive engine cooling systems, and so it is recommended to use the same fluid (anti-freeze + corrosion inhibitor) but in lower concentration. Initially the thermal exchange is less efficient than with water, as the fluid is more viscous due to the glycol (more power is needed for turbulent flow). However, for long term use, a coolant (such as those used in cars) is the most effective solution (no corrosion or deposit, low erosion from cavitation).

In the case of coolants for open tower circuits, there is a need for chemical treatment to prevent build-up of micro-biological organisms that could cause disease and respiratory problems.

Molding Cycle

As previously mentioned, the fact that Delrin® is a highly crystalline material leads to a molding cycle different from that of amorphous polymers. For Delrin®, a molding cycle generally consists of the following phases, as shown in **Figure 7.2**:

Figure 7.2. Molding Cycle for Delrin®



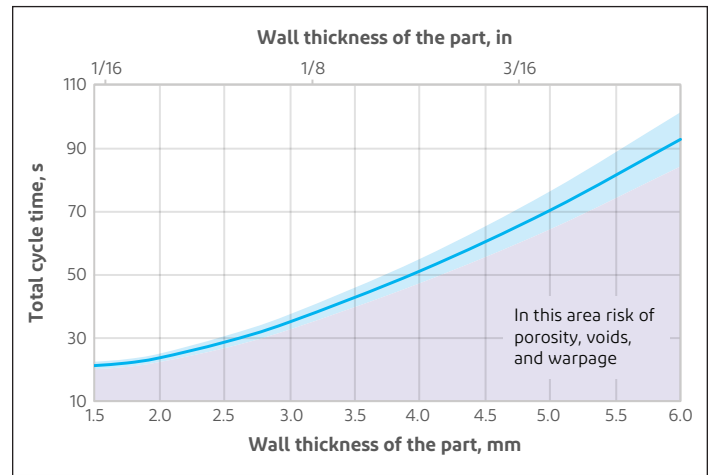
- A. *Mold Open Time*. This includes the Opening Time, the Ejection Time and the Closing Time.
- B. *Filling Time or Injection Time*. Molten resin is introduced into the mold in a “dynamic filling phase.”
- C. *Hold (Pressure) Time*. During this “packing phase,” the resin is solidified under pressure, while additional resin is introduced into the mold to compensate for volume shrinkage occurring within the mold.
- D. *Screw Retraction Time or Plasticization Time*. The screw rotates and prepares new molten material for the next shot.
- E. *Cooling Time*. Since the part is crystallized (solid) and ready to be ejected at the end of the HPT, there is no need for a cooling time; hence the cooling time is only the Screw Retraction Time plus a short safety time, generally, 1 second.

The Overall Cycle Time (OAC) for Delrin® is the addition of the various times set for each of the molding operations.

Note: Frequently the sum of the Filling (Injection) Time and the Hold (Pressure) Time is defined as Screw Forward Time (SFT), as noted in Delrin® literature.

The cycle estimation graph in **Figure 7.3** shows a range of total cycle times that have been used for good quality molding of Delrin® in parts of various thickness. The actual cycle will be close to the lower limit when a high productivity resin such as Delrin® 900P is used and when end-use requirements are less stringent.

Figure 7.3 Estimation of Overall Molding Cycle Times for High Quality Molding of Delrin® Parts



Injection Phase

The optimum filling time is dependent on part design, wall thickness, flow length, shot volume, gate and runner design. It is important to provide adequate venting to avoid burn marks.

The injection pressure during the dynamic mold filling phase is a function of:

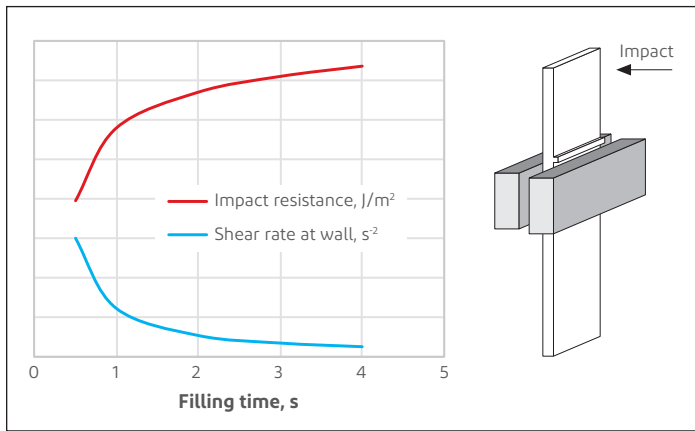
- The programmed injection speed
- Material viscosity at its melt temperature
- Material crystallization speed and mold temperature
- Cavity flow resistance (geometry, wall thickness, flow length)

The resulting injection pressure may be much lower than pack pressure, i.e., for thick parts and short flow length, or even much higher than pack pressure, i.e., for thin parts and long flow length.

As rule of thumb, a filling time of 1 sec per mm (0.04 in) of part thickness is a good starting point for fill speed setting. The surface aspect will govern this adjustment. Higher and more uniform surface gloss can be obtained if the injection rate is fast enough to allow the cavity to be filled before the resin begins to solidify, although localized surface flaws, such as jetting and gate smear, are often reduced by decreasing the initial injection rate.

If maximum part toughness is required for the application, the shear applied to the material in the runner(s) and part should be checked to ensure optimum molding performance and part properties. **Figure 7.4** shows the impact performance of a 2 mm (0.08 in) part versus the shear during filling.

Figure 7.4 Shear Strain Rate at the Wall (s⁻¹) and Impact Resistance (kJ/m²) as Function of the Filling Time



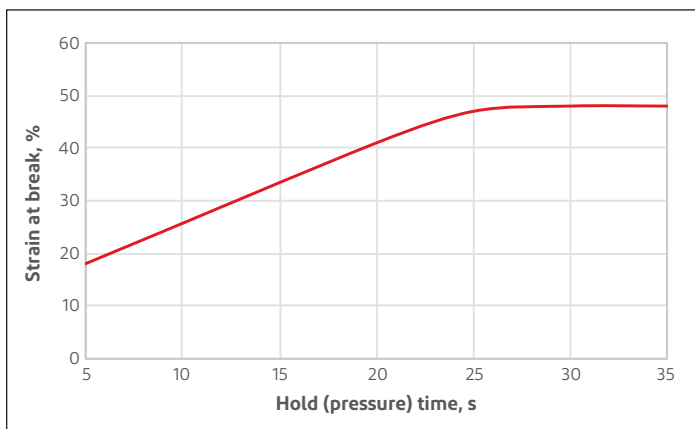
With non-optimum gate designs (conical, excessive gate length), shear in the gate may become an important limiting factor for part toughness.

With the optimum gate design presented in the mold design section (dimensions that allow optimum packing during crystallization, gate length <0.8 mm [1/32 in]), in most cases the shear at the gate has no effect on part performance. Flow analysis should be performed to check the shear at the gate for molding very large parts only.

Pack or Hold Pressure Phase

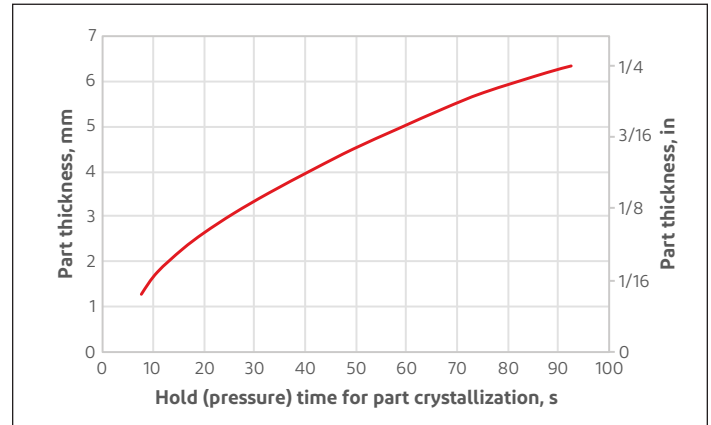
The recommended Hold (Pressure) Time (HPT) for Delrin® is the time for the molten polymer to fully crystallize in the mold cavity. This parameter is crucial for the mechanical performance of the final part. **Figure 7.5** shows the effect of shortened HPT on strain at break properties, as tested on Delrin® 500 family grade resin.

Figure 7.5 Hold (Pressure) Time Versus Strain at Break of a Delrin® 500 Family Grade



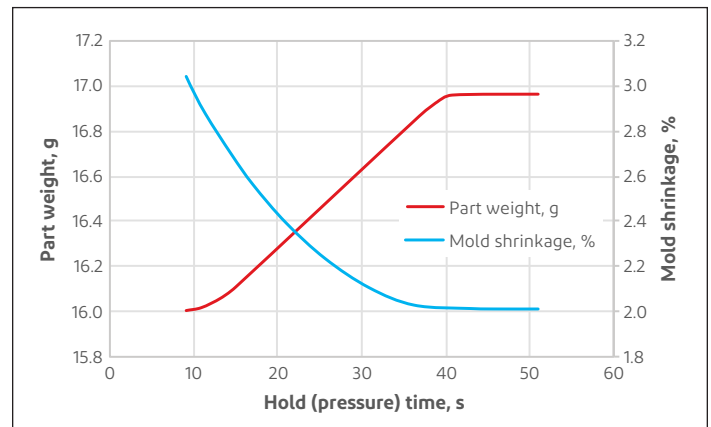
As the crystallization (solidification) leads to a large volume drop (≈18%), more melted material has to be pushed into the cavity during all the HPT. This leads to special design rules for the gate and runners, as noted in the Molds section, so that the gate will not freeze before the cavity is properly packed. The HPT is obviously a function of the part thickness, as graphically shown in **Figure 7.6**.

Figure 7.6 Optimum Hold (Pressure) Time Per Part Thickness, as Measured by Part Weight for a Delrin® 500 Family Grade



The correct pack pressure time is easy to determine on the injection molding machine. Several different pack times are set 0.5 to 1.0 second apart, depending on the required resolution, and the resultant moldings weighed on a laboratory balance after removing the runner and sprue. The optimum pack pressure time will be in the region where there is no longer any change in the weight of molded parts (**Figure 7.7**). This pre-supposes that the gate has been correctly positioned and designed.

Figure 7.7 Hold (Pressure) Time Versus Part Weight and Mold Shrinkage of Delrin® 500 Family



Similar to other semi-crystalline polymer, the pack pressure level should be constant over the pack pressure phase time.

Optimum hold pressures for Delrin® acetal resins lie in a range of 60–110 MPa (8.7–16.0 kpsi) to achieve a homogeneous crystallization. If higher or lower pressures are used in special conditions, they tend to lead to lower part performance. **Table 7.1** shows the hold pressure range recommended for the various types of Delrin®.

Table 7.1 Recommended Hold Pressure Ranges by Viscosity Family

Resin Type	Hold Pressure, MPa (kpsi)
High Viscosity	90–110 (13.0–16.0)
Medium and Low Viscosity	80–100 (11.6–14.5)
Toughened	60–80 (8.7–11.6)

Cooling Time

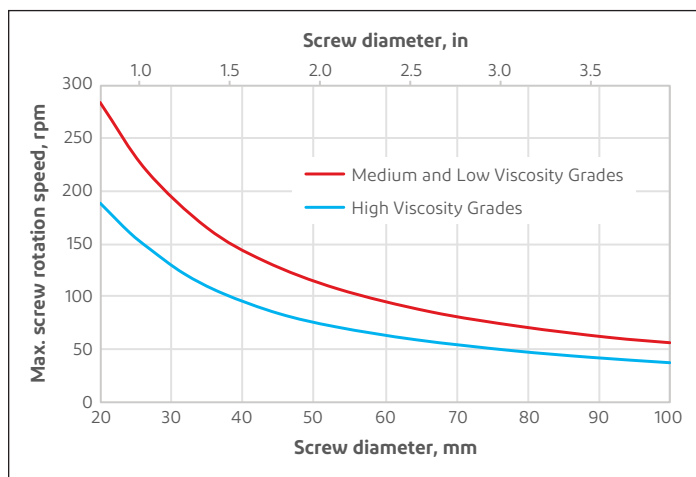
Cooling time is an important parameter for the injection molding of amorphous polymers. The situation is completely different with Delrin®. At the end of a correctly set and efficient hold pressure time (HPT), the Delrin® part is crystallized and solid. There is no need for further cooling time and the part could in principle be ejected immediately from the mold. This can be demonstrated by stopping the cycle at the end of the HPT and ejecting the part immediately. Only when there are high forces because of the ejection process it might be necessary to have an additional cooling time to lower the part temperature and therefore increase the stiffness of the part. In order to optimize the cycle time, the cooling time is usually set just longer than the plasticizing time.

In most practical cases the part is ejected after the screw retraction time, so the cooling time (**Figure 7.2**) is simply the screw retraction time plus a small safety margin, usually 1 second. An exception is the case of machines with shutoff nozzles, where part ejection can take place during the screw rotation. This theoretically gives shorter cycles, although practical problems may arise and limit productivity (see Nozzles for more information).

Screw Retraction Phase

Screw rotation speed behaves as a “thermal setting,” because the rotation of the screw will “shear” the material and supply around half of the calories needed to melt and heat Delrin® to the recommended melt temperature range. As with all polymers, Delrin® is sensitive to shear and a maximum of 0.2 to 0.3 m/s of screw peripheral speed is recommended. **Figure 7.8** demonstrates the relationship between optimum screw rotation speed for high viscosity Delrin® (100 family grades) and low viscosity Delrin® (500 to 900 family grades) as a function of screw diameter.

Figure 7.8 Maximum Screw Rotation Speed as Function of Screw Diameter



Low to no back pressure should be used. Increasing back pressure increases the work done by the screw on the molten polymer, incrementally increasing melt temperature and uniformity. Where melt quality is marginal, high back pressure may reduce unmelted particles, but it will not substantially increase melt quality. The effect of back pressure on reinforced resins is to produce additional screw work which can cause fiber breakage that may cause a reduction in the physical properties of the molded part. Only melting of highly viscous Delrin® may require some back pressure to avoid the screw worming back, leading to inconsistent shot volume and pad.

Increasing back pressure also increases recovery time. The lowest possible back pressure consistent with good melt quality is recommended during the molding of DuPont thermoplastic resins. Therefore, back pressure should be used only when increasing cylinder temperature or other changes are not effective or possible.

Normally only slight melt decompression is required in order to avoid leakage of material from the nozzle. The use of decompression helps to prevent nozzle drool from hot-runner tools and to stop vent discharge in vented cylinders.

Use of excessive decompression can cause air to be sucked in through the nozzle. This can result in oxidation of material which will be seen as areas of discoloration in the molding. Another consequence could also be the injection of a cold slug in the next shot, leading to surface defect and to part weakness.

Evaluation of Melt Quality

Below are two quick and easy tests to evaluate the melt quality delivered by the injection unit. Although the result is linked with the temperature setting of the injection unit, it is also highly dependent on the design of the injection unit.

Foaming Test

The foaming test is recommended to determine the quality of the resin after melting in the injection unit, i.e., the quality of the resin AND the quality of the injection unit.

Procedure:

1. When the machine is running in cycle, stop the machine after screw retraction for 3 minutes for pigmented Delrin® (10 minutes for natural material).
2. Purge at low speed (to avoid hot splashes) into a cup and observe the molten material for 1 or 2 minutes. Then put the molten material in a bucket of water.
3. Then recharge the screw and wait 2 more minutes (10 more minutes for natural material).
4. Repeat step 2.

An unstable melt will grow (foam) during the observation and float in the bucket. A stable melt will stay shiny with a tendency to shrink during the observation, and will sink in the bucket.

Foaming resin will quickly cause mold deposit and will accelerate screw deposit, which may lead to black speck contamination.

This technique is useful to evaluate non-DuPont color systems (color masterbatches, liquid coloring).

The foaming test can also be used to detect inadequate quality of the injection unit (e.g., problems of throat cooling and consequent overheating, excessive nozzle temperature, hold-up spots, etc).

Unmelt Test

The unmelt test is recommended to evaluate melt homogeneity:

- When the press is running on cycle, stop at the end of a cycle and purge one shot
- Charge the screw immediately with the shot volume used and purge again
- Repeat the operation until detection of lumps/irregularities in the purge coming out of the nozzle

If such lumps/irregularities appear after less than 3 purges, the risk of unmelt is very high and should be dealt with by increasing cylinder temperature, by lowering screw RPM and by increasing back pressure. If such changes lengthen the cycle time too much, a more appropriate screw design should be used. If lumps/irregularities appear after 3 purges but before 6, the situation is acceptable, but there is not much safety margin. If they appear after 6 purges, there is a very low risk of unmelt. Grade-specific injection molding conditions can be found on www.delrin.dupont.com.

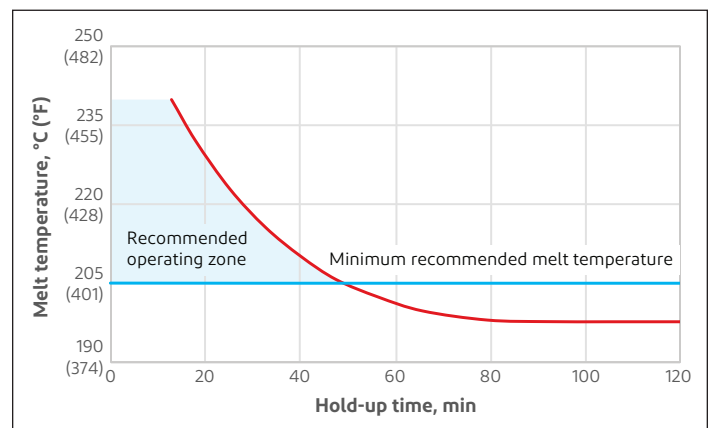
8. MATERIAL BEHAVIOR

Thermal Stability During Processing

One difference between amorphous and crystalline material is the “melting” behavior. The amorphous polymer starts softening just after T_g and presents a continuous change in viscosity. This gives a very large temperature range to operate (but a large variation of viscosity with temperature). In contrast, the crystalline polymer stays solid up to the melting point and suddenly melts to the liquid phase at high temperature. This limits the processing range of temperature between unmelt and thermal degradation (specifically for Delrin® 190–250 °C [374–482 °F]).

The second factor is the time the material stays at that temperature. For all polymers, the molecules can withstand a certain time at a certain temperature before degradation can start. This acceptable time limit becomes shorter when the temperature is higher. The typical behavior of Delrin® is presented in **Figure 8.1**. Degradation of Delrin® will result in generation of gases which cause bubbles in the melt, splay on parts, mold deposit, yellow and brown marks on the parts.

Figure 8.1. Effect of Temperature on Hold-up Time of Delrin® 500P



The average residence time (or Hold-UpTime, HUT) in the injection unit is linked to the amount of polymer in the cylinder, the shot weight and the cycle time and can be calculated with the following equation:

$$\text{Average HUT} = \frac{\text{weight of resin in cylinder}}{\text{shot weight}} \times \text{cycle time}$$

A quick approximation can be done by:

$$\text{Average HUT} = \frac{\text{maximum screw stroke} \times 2}{\text{current screw stroke}} \times \text{cycle time}$$

With a screw stroke of 1 diameter (a small shot) and a cycle time of 1 minute (a very long cycle), the average HUT is equal to 8 min. According to the degradation curve shown in **Figure 8.1**, Delrin® should be stable enough for injection-molding with this HUT at a melt temperature of 240 °C (464 °F). Some customers have experienced molding Delrin® successfully at that temperature.

At the recommended melt temperature of 215 °C (419 °F), the maximum HUT is over 30 min and Delrin® (standard grades) is thermally stable even under these extreme conditions.

There are 3 main potential causes of degradation:

- **Material trapped in hold-up spots.** In the injection unit, trapped molten material will stay for very long time in any dead spots and will start to degrade. So all of the injection unit (screw, back flow valve, adaptor, nozzle, and hot runner) should be designed to avoid hold-up spots (see following recommended design).
- **Material sticking to “hot” steel.** Due to the high viscosity of polymers, the speed next to the steel of the injection unit (screw, back flow valve, adaptor, nozzle, and hot runner) is almost zero and the residence time is almost infinite (as evidenced by how long it takes to change colors in an injection unit). Whereas inside the barrel the molten polymer is cleaned by the screw and the valve, inside all other areas the material will stick to the walls. To withstand a very long residence time, the steel in contact should be controlled at a temperature lower than 190 °C (374 °F) (**Figure 8.1**).
- **Chemical degradation.** Contamination (e.g., PVC, flame retardant resins, acid generating resins), incompatible coloring systems (acid or basic pigments), contact with copper (pure, alloys, grease) will accelerate the thermal degradation of molten Delrin® in the injection unit. Note that mold components in copper or copper alloys (such as copper-beryllium) do not cause any degradation and have been used for years without problems.

Low Emission Molding

For parts molded with extremely low emission resins (“E”-resins) additional recommendations should be taken into consideration to achieve the lowest possible emissions values on the molded parts.

To reduce emissions, as a general rule, the material should be processed as “smoothly” as possible:

- The melt temperature of “E” resins should be at 205 °C (401 °F) measured directly in the melt.
- High shear due to high injection speed or high dosing speed should be avoided.
- Backpressure should be set as low as possible.
- Drying of the resin before processing can help with standard resins to reduce formaldehyde emission. For – “E” resins drying may not have this effect, or may have a contrary effect.
- Molded parts should be stored a minimum 24 hours in fresh air before packing.
- The use of masterbatch can have a significant influence on the formaldehyde emission of the molded parts

Viscosity and Rheological Behavior

Melt viscosity determines to a large extent the ability to fill the mold cavity. High viscosity means difficult flow through thin sections and higher injection fill pressure.

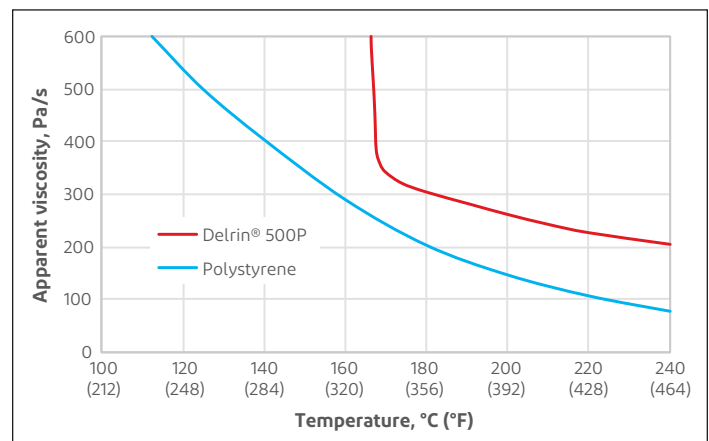
Temperature and shear rate are crucial parameters when considering the viscosity of molten polymers, and they should always be specified together with a value for melt viscosity.

For polymers consisting of linear molecules like Delrin®, the viscosity is also in direct relation to the average molecular weight.

Influence of Temperature

Generally, liquids become less viscous when increasing in temperature. This is also true for molten thermoplastics. However, crystalline and amorphous polymers behave differently, as shown in **Figure 8.2**. The curves for Delrin® and polystyrene were both obtained by gradually reducing the temperature of the materials from 230 to 100 °C (446 to 212 °F). Two differences are worth mentioning. First, at temperatures above 180 °C (356 °F), the dependence of viscosity on temperature is more pronounced for the amorphous polystyrene than for Delrin®; therefore, increasing the melt temperature of Delrin® does not greatly improve its ability to flow through a thin section. Second, below 170 °C (338 °F) the viscosity of Delrin® rises sharply because the material crystallizes within a few degrees of that temperature.

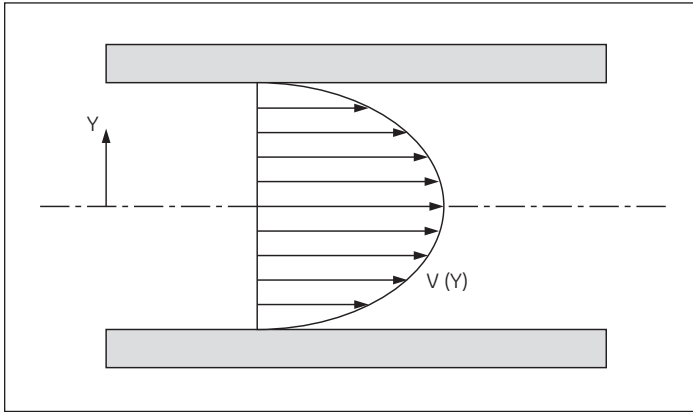
Figure 8.2 Viscosity/Temperature Curves for Delrin® Medium Viscosity Grade and for Polystyrene at a Constant Shear Rate of 1000 s⁻¹ (Temperature Reduced from 230 to 100 °C [446 to 212 °F])



Influence of Shear Rate

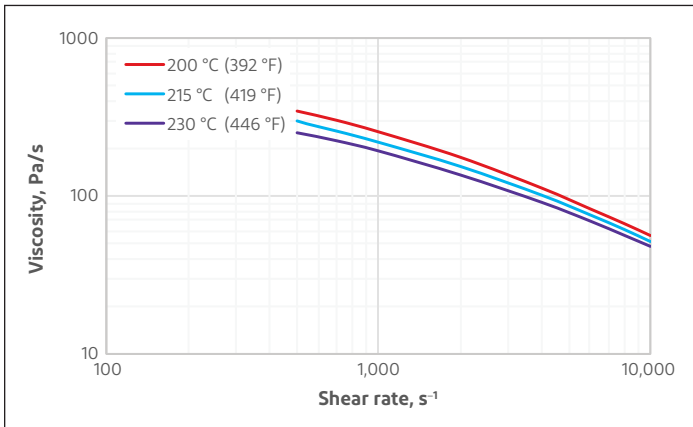
The shear rate characterizes the rate of deformation of the of the Delrin® Grades material and is defined as the derivative of the velocity over the direction perpendicular to flow (**Figure 8.3**); in other words, the shear rate is proportional to the variation of speed within the part thickness. So it depends on the velocity of the flow and on the geometry of the flow channels.

Figure 8.3 Approximate Shape of the Velocity Distribution Between Two Parallel Plates. The Shear Rate is the Derivative $dv(y)/dy$.



For Delrin®, the melt viscosity decreases considerably when the shear rate increases, as shown in **Figure 8.4**. This effect is more important than the differences resulting from variations of the melt temperature within the processing window for injection molding.

Figure 8.4 Viscosity versus Shear Rate of Delrin® 500 Family Grade at Three Temperatures



Influence of Molecular Weight

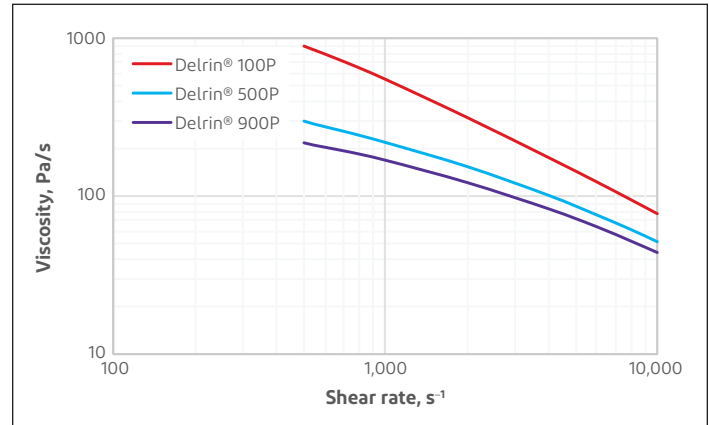
Delrin® is available in four grades of molecular weight. They are coded according to their ability to flow, as measured by MFR (melt flow rate) (see **Table 8.1**). High values mean easy flow and ability to fill thin parts, whereas low values mean high viscosity, high molecular weight and high toughness (impact resistance, elongation at break).

MFR is a measurement performed at low shear rate, but the relative differences between the grades are maintained at high shear rates, as shown in **Figure 8.5**.

Table 8.1 Viscosity, Flow and Molecular Weight (Mw) of the Delrin® Grades

Grade Family	MFR (190 °C/ 2.16 kg)	Ease of Flow	Toughness, Mw	Spiral Flow Length (215 °C/100 MPa/2 mm) 90 °C mold temperature
100	2.3	lowest	highest	170 mm (6.7 in)
300	7	↓	↑	240 mm (9.4 in)
500	14			295 mm (11.6 in)
900	24	highest	lowest	350 mm (13.8 in)

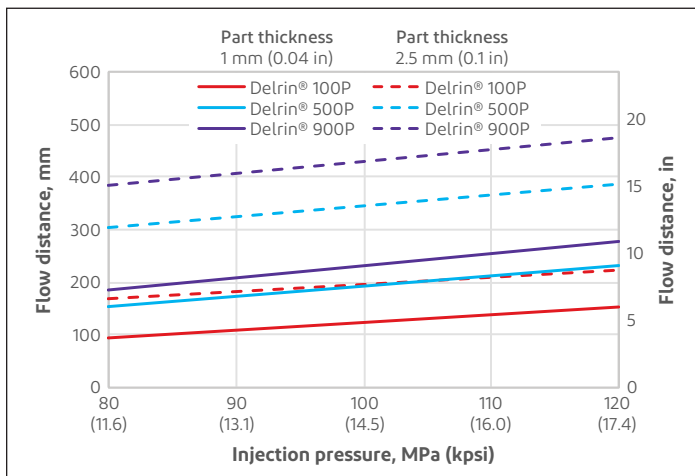
Figure 8.5. Viscosity versus Shear Rate for Various Grades of Delrin® at a Constant Temperature of 215 °C (419 °F)



Ability to Fill

Melt viscosity largely governs the ability of a resin to fill a mold. Delrin® acetal resins range in melt viscosity from the Delrin® 900 family, the lowest in viscosity (or most fluid), to the Delrin® 100 family, the highest (or most viscous). The viscosity of Delrin® does not decrease rapidly as melt temperature increases, in contrast to amorphous thermoplastic resins. Moreover, increasing melt temperature will not greatly improve the ability of Delrin® to fill a thin section. In addition to the properties of the resin, the molding conditions and cavity thickness determine the distance of flow. **Figure 8.6** shows the maximum flow distances that can be expected at two cavity thicknesses for Delrin® acetal resins as a function of injection fill pressure. The relationships shown in **Figure 8.6** show the effect of viscosity and melt flow rate on flow distance. These comparisons were made in an open-ended snake flow mold with no gate restriction. Obstructions in the flow path, such as sudden changes in flow direction or core pins, can significantly reduce the flow distance.

Figure 8.6 Maximum Flow Distance of Delrin® Acetal Resins



Dimensional Considerations

For amorphous thermoplastics, shrinkage is caused primarily by contraction of the molded part as it cools to room temperature.

In semi-crystalline thermoplastics, shrinkage is also influenced considerably by the crystallization of the polymer. The degree of crystallization depends largely on the transient and local temperature changes in the molding. High mold temperatures and heavy wall thickness (high heat content of the melt) promote crystallization and therefore increase shrinkage.

Optimum runner and gate design, as well as adequate pack pressure time are necessary in order to achieve minimum shrinkage with semi-crystalline polymers.

Delrin® acetal resins have good dimensional stability, compared to other polymers, over a wide range of temperatures and in the presence of moisture, lubricants, or solvents. They find extensive use in industry for the fabrication of precision gears, bearings, housings and similar devices, because of their unique combination of dimensional stability with other properties, such as fatigue resistance and tensile strength. However, as with all materials of construction, there are factors affecting the dimensional stability of Delrin® which must be considered when close tolerances are essential.

Fundamentals of Dimensional Control

The dimensions of a molded part are determined primarily by the dimensions of the cavity, and secondly by all those variables that affect resin packing and crystallinity (for example hold pressure, HPT, mold temperature). It may seem obvious to mention cavity dimensions as the main factor for part dimensions; however, experience has demonstrated that dimensional problems are often addressed by changes in molding conditions, generally, with limited success. Isotropic dimensional problems can in

principle be corrected by changes to hold pressure. In the more frequent cases where a few dimensions are out of specification, attempts to correct with the molding parameters generally reduce the acceptable processing window, leading to a higher risk of rejects. As such, if the molding conditions to maximize the part weight and, as a consequence, part performance do not resolve dimensional issues in the part, it is necessary to consider modifying the dimensions of the cavity to accommodate for the expected shrinkage.

Mold shrinkage and post-mold shrinkage occur as natural consequences of the molding process. They influence the tolerances that can be obtained for molded parts. Data collected on standard parts (typically, rectangular solids) on these effects are presented in this section.

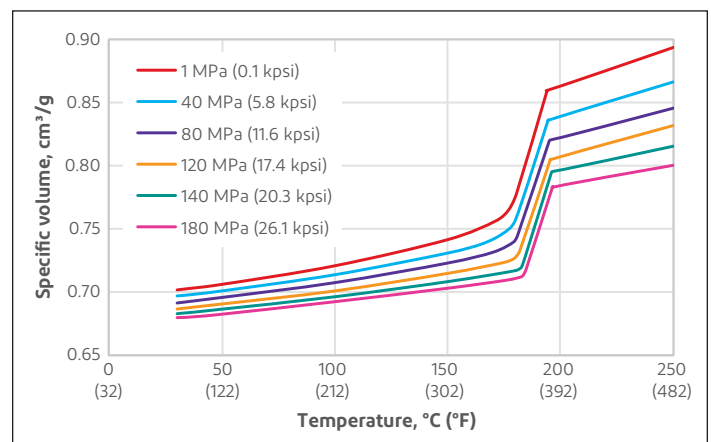
Further dimensional variations in molded parts of Delrin® can arise from changes in the temperature or nature of the surroundings. Reversible changes result from thermal expansion or contraction and from absorption of water or other solvents. These are discussed later in this section, under *Environmental Changes*.

Irreversible changes in dimension occur when polymer chains frozen in an unstable condition move towards a more stable state. An example is when parts molded in a tool at low mold temperature are exposed to elevated temperatures. These changes are discussed under *Post-Mold Shrinkage and Annealing*.

Mold Shrinkage

Mold shrinkage is the shrinkage that occurs within 24hr of molding. It is defined as the difference between cavity and actual part dimension, both measured at room temperature. It is due to the difference in specific volume of Delrin® at the crystallization temperature and its specific volume at room temperature (see PVT Diagrams below in **Figure 8.7**).

Figure 8.7 Pressure-Volume-Temperature (PVT) Diagram for Delrin® 500P



The typical mold shrinkage of Delrin® resins is between 1.7 and 2.2%, except for the supertough and fiber-containing grades which have a lower shrinkage. The shrinkage for an actual part depends on its design and on the molding conditions, as described in more detail below. Shrinkage data for Delrin® grades can be found on our website.

Factors Affecting Mold Shrinkage

Mold shrinkage is dependent on the factors that affect the crystallinity of Delrin®. These include:

- hold pressure
- hold (pressure) time
- mold temperature
- part thickness
- gate dimensions

Table 8.2 summarizes the effect of these parameters on mold shrinkage. They are discussed in more detail below.

Table 8.2 Effects of Parameter Changes on Mold Shrinkage

As the Below Parameter is Increased	Effect on Shrinkage	Remarks
Hold (Pressure) Time (HPT)	↓	up to optimum HPT, then no effect
Hold Pressure	↓	
Mold Temperature (cavity)	↑	but post-mold shrinkage ↓
Part Thickness	⇒ or ↓	if all settings optimized
Gate Thickness	↓	up to optimum thickness, then no effect
Melt Temperature	⇒	if mold temperature is kept constant and HPT is optimized

Key parameters affecting mold shrinkage: Symbol ↑ means that the shrinkage increases when the value of the parameter increases, and the opposite for the symbol ↓. Symbol ⇒ means that there is no effect on shrinkage provided that the conditions listed under “Remarks” are met.

Furthermore, mold shrinkage is also highly dependent on the geometry of the part and on the flow pattern of the resin. Experiments have been done in our laboratory with 180 x 27 mm plaques with thicknesses from 1.5 to 6 mm. Four values of shrinkage were measured, close to and far from the gate, parallel and perpendicular to the flow. For most grades of Delrin® it is observed that the shrinkage is higher far from the gate than close to the gate (typically by 0.1 to 0.3%), and that the shrinkage in the flow direction is about 0.1% higher than transverse to the flow.

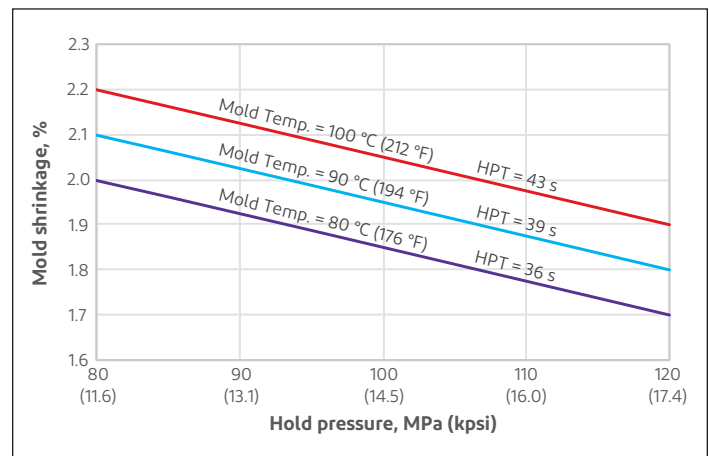
Pressure

Pressure has two functions in the molding process:

1. Transfer the molten polymer from the injection unit into the mold. This “injection fill pressure” is needed only to overcome the resistance to flow of the polymer from the injection unit to the cavity. Usually this is a high speed process (dynamic phase of the screw).
2. Control the packing and crystallization process. The “hold pressure” pushes more material into the cavity to compensate for the volume reduction that occurs in the polymer during crystallization. This is a low speed process (slow motion of the screw). This phase is more important for dimensional stability since it helps maintain a uniform and gradual crystallization. When a lower hold pressure is used, it will pack less material into the cavity and the shrinkage will be higher. This is shown in **Figure 8.8** for three mold temperatures.

Small changes of hold pressure may be used to help fine tune the dimensions of a part, because this parameter is essentially independent and has relatively small adverse effects. Note that hold pressure should be constant during the whole packing time.

Figure 8.8 Effect of Hold Pressure on Mold Shrinkage at Three Mold Temperatures, for Delrin® 500P



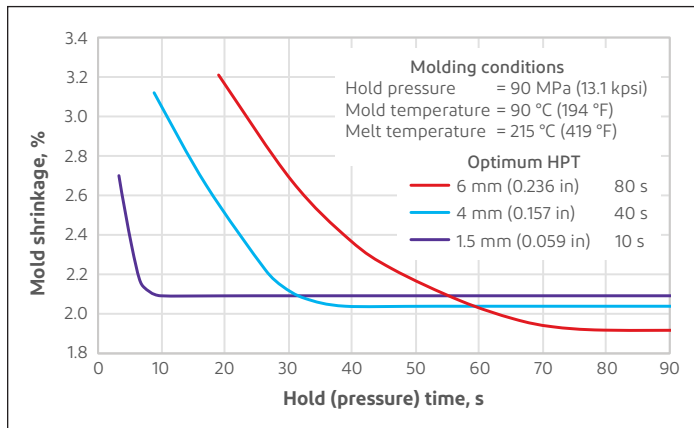
Hold (Pressure) Time (HPT)

Hold (Pressure) Time is the time during which the hold pressure is applied. The HPT is important for the value of shrinkage and its uniformity over the part. **Figure 8.9** shows the effect of HPT on mold shrinkage for Delrin®.

When the HPT is below the optimum value required for the specific part (see Pack or Hold Pressure Phase), the packing process is interrupted before completion and mold shrinkage is higher than its optimum value. Additional side-effects of a short HPT include porosity, voids, warpage, sink marks, and lower mechanical properties.

In contrast, any increase of HPT above its optimum value would have no effect on mold shrinkage, because the part, (and gate), are already solidified.

Figure 8.9 Effect of Hold (Pressure) Time on Mold Shrinkage of Delrin® 500P



Mold Temperature

Mold temperature influences mold shrinkage through its effect on cooling rate and crystallization temperature of the molten polymer. The effect of mold temperature on shrinkage is also shown in **Figure 8.8**.

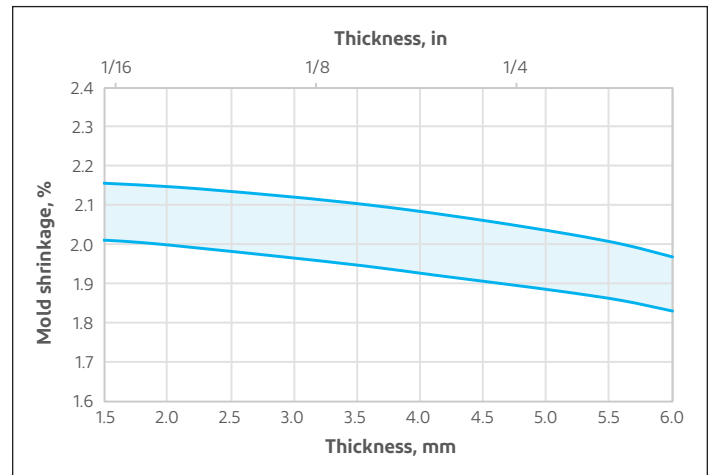
At high mold temperatures, the polymer crystallizes slowly. In such conditions the mold shrinkage is high, but since the crystallization is more complete, a better long-term dimensional stability is to be expected for the molded parts (less post-mold shrinkage).

Low mold temperatures, on the other hand, tend to cool the polymer too fast, leading to a lower level of crystallization. This results in lower mold shrinkage and better toughness. However, in the long term, higher dimensional variations leading to build up of internal stresses will occur, particularly if the part is exposed during its end-use life to temperatures exceeding the mold temperature at which the part was molded.

Part Thickness

As shown in **Figure 8.10** for grades from the Delrin® 100 and 500 families, the thickness has a minor influence on mold shrinkage, provided that the gate dimensions and the hold (pressure) time are correct for each thickness. Note that, to optimize toughness, the mold temperature is reduced from 90 °C (194 °F) for the standard grades to 50 °C (122 °F) for the toughened grades (without leading to a high post-molding shrinkage).

Figure 8.10 Average Mold Shrinkage Versus Thickness for Standard Delrin® Grades



For parts of uniform wall thickness, the mold shrinkage tends to be uniform. In the case of variable thickness, shrinkage will tend to be nearly uniform if the part is gated into the thickest section, if the gate is properly sized and if the Hold (Pressure) Time equals or exceeds the gate freeze time. When these criteria are not met, the mold shrinkage tends to be greater for larger sections, with possible problems of voids, warpage, sink marks and lower mechanical properties.

Gate Dimensions

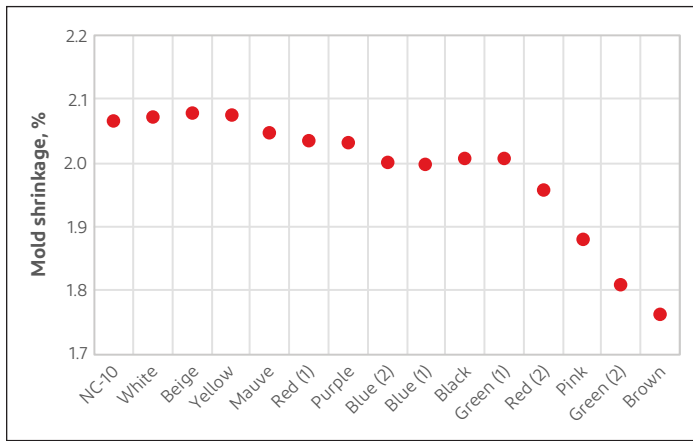
Adequate gate dimensions are required to ensure proper packing of the part. More details are provided in the Gate Design section. When the thickness of the gate is smaller than its optimum value, mold shrinkage will increase due to the premature solidification of the resin at the gate. This situation is then equivalent to a shorter Hold (Pressure) Time, and the approximate effect on shrinkage can be observed in **Figure 8.9**. In this range the mold shrinkage is not stable, and it is very difficult to control. The resulting warpage could even make difficult the measurement of certain dimensions of the part.

Effect of Pigments

The presence in the melt of crystallization nuclei such as pigments and regrind can have an influence on crystallization and consequently on mold shrinkage.

An accurate study has been carried out to evaluate the effect of various types of pigments on the mold shrinkage of Delrin®. It appears, as depicted in **Figure 8.11**, that pigment systems giving the same resin color may have a different effect on mold shrinkage and part dimensions.

Figure 8.11 Effect of Selected Pigments on Mold Shrinkage of Delrin® 500P



Note: This study has been conducted with standard 2 mm bars using the recommended molding conditions of Delrin® 500P. The shrinkage values shown here should not be considered valid for all parts of different geometry and/or molded in different molding conditions.

Post-Molding Shrinkage

Post-molding shrinkage is defined as the shrinkage which takes place more than 24 hours after molding. It is a consequence of continued crystallization and relaxation of molded-in stresses, where the resin moves towards a more stable state.

The rate of shrinkage is time/temperature dependent and is greatly accelerated as the temperature of the part is raised. The amount of shrinkage is dependent primarily on molding conditions and wall thickness. The post-mold shrinkage of parts molded in Delrin® after exposure for 1,000 hr (after molding) in air at various temperatures can be estimated from **Figure 8.12**. The data for moldings of three different thicknesses are plotted on separate graphs with each graph presenting a family of curves for several mold temperatures.

Parts molded with the recommended mold temperature (90 °C [194 °F]) or higher will have a low post-mold shrinkage, which ensures good dimensional stability over the lifetime of the part.

However, parts molded with a cold mold (<80 °C [<176 °F]) will have a higher post-mold shrinkage, because fast cooling leaves the Delrin® in an unstable crystalline state and results in more significant recrystallization. If such Delrin® parts are then exposed to high temperatures, the recrystallization causes a high and rapid post-mold shrinkage.

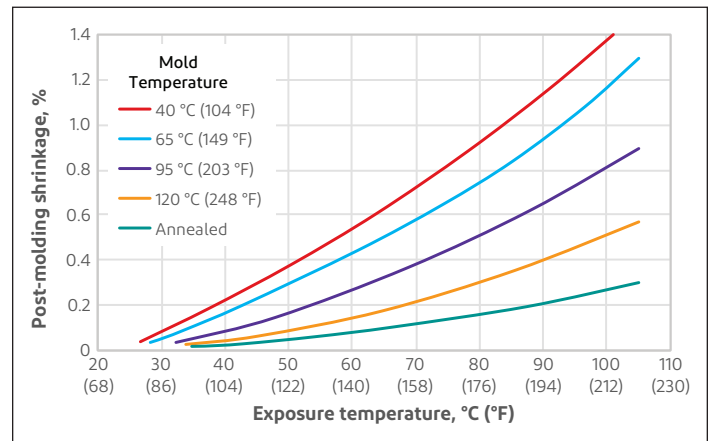
Remarks:

- For parts requiring tight tolerances and exposure to elevated temperatures for prolonged periods of time, it is strongly recommended to use high mold temperatures (up to 120 °C [248 °F]). This provides a more effective solution than annealing a part molded at low mold temperature.

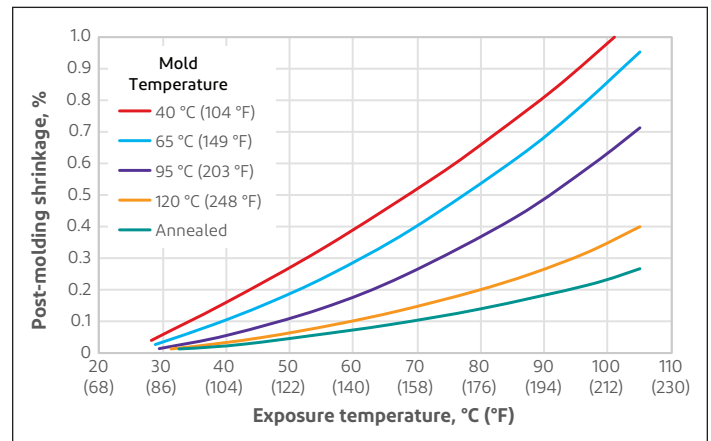
- For exposure at moderate temperatures, good dimensional stability and part performance can be achieved using a 90 °C (194 °F) mold temperature.
- Years of experience with many applications have shown that parts of Delrin® acetal resin molded at our recommended mold temperature (90 °C [194 °F]) will exhibit negligible postmolding shrinkage in most applications.

Figure 8.12 Post-Molding Shrinkage of Delrin® Acetal Resins in Air after Exposure for 1,000 hr

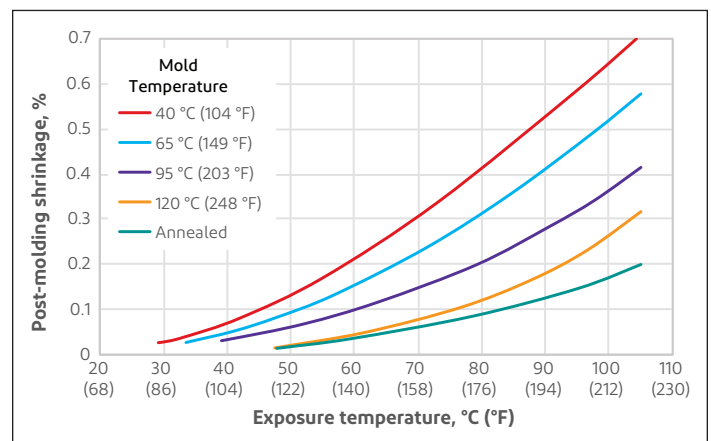
a. Thickness—0.8 mm (1/32 in)



b. Thickness—1.6 mm (1/16 in)



c. Thickness—3.2 mm (1/8 in)



Annealing

Annealing is occasionally used to accelerate stress relaxation and dimensional stabilization of parts. It is a complex process and should only be used when molded parts require very tight tolerances and exposure to high temperatures for prolonged periods.

Annealing is also suggested as a test procedure in setting up molding conditions on a new mold, to evaluate post-molding shrinkage and molded-in stresses. The changes in dimensions during annealing will closely represent the ultimate change in part size in use.

When dimensional precision is a prime requirement, the use of a high mold temperature (90–120 °C [194–248 °F]) is strongly recommended. Attempts to reach good dimensional stability by annealing parts molded in a cold mold (<80 °C [<176 °F]) will lead to high post-molding shrinkage and may introduce stresses during the re-crystallization process, resulting in uncontrolled deformation.

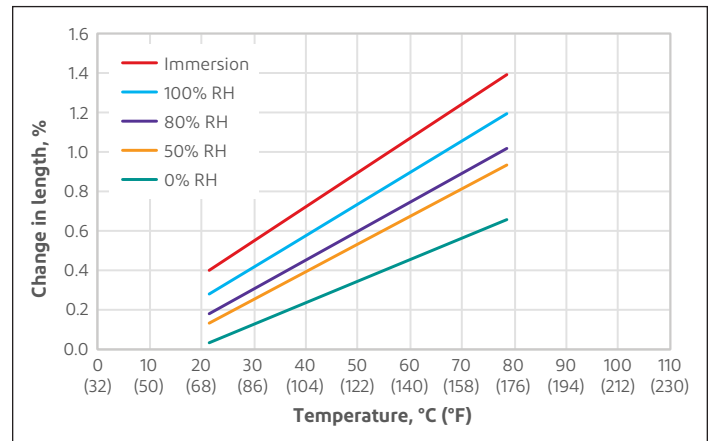
Annealing should be performed in air or in inert mineral oils at 160±3 °C (320±5 °F), for 30 minutes + 5 minutes per each 1 mm (0.04 in) of wall thickness. Overheating and hot spots should be avoided, and parts should not contact each other or the walls of the oven/ bath. Parts should be left in the oven to cool slowly until 80 °C (176 °F) is reached. Stacking or piling, which may deform the parts while they are hot, should be delayed until the parts are cool to the touch. This procedure was used to obtain the results shown in **Figure 8.11**, and permits evaluation of the ultimate dimensional changes that a part is likely to experience in normal use.

To simply stabilize parts for continuous high temperature use (<90 °C [<194 °F]), parts may be heated to 90 °C (194 °F) for up to 24 hr. Post-molding shrinkage of around 0.1 to 0.2% will then be seen if the parts were molded in a mold at 90±10 °C (194±18 °F).

Environmental Changes

Part dimensions of Delrin® acetal resin change with the environmental temperature and with the absorption of small amounts of water. Data concerning dimensions for various Delrin® acetal resins are plotted in **Figure 8.13**, which combines the effects of moisture content and temperature. The graph shows several lines representing different exposure conditions with respect to moisture (50% RH, 80% RH, 100% RH, and immersion).

Figure 8.13 Environmental Dimensional Change of Standard Delrin® Grades



Dimensional Tolerances

Taking into account mold dimensions and processing variability, experience suggests that the following dimensional tolerances are achievable with good molding practice:

Dimensions up to 150 mm (5.9 in):

- ±0.15% for precision molding
- ±0.3% for technical molding

Dimensions above 150 mm (5.9 in):

- ±0.25% for precision molding
- ±0.4% for technical molding

Molds

For multi-cavity molds, the tool making tolerances are important. They have a direct effect on the dimensional tolerance of the part. As an example, for a mold dimension of 30 mm (1.2 in) manufactured to within ± 0.01 mm (0.0004 in), experience has shown that dimensional consistency better than ± 0.03–0.04 mm (0.0012–0.0016 in) cannot be expected for parts from different cavities in a single shot.

Molding Conditions

Parts molded under recommended conditions (gate, runner, nozzle, screw, machine parameters) as defined in the molding guide are subject to small shot-to-shot variations in dimensions. Any change in machine parameters or conditions will affect dimensional tolerance. For example, a colder mold leads to higher post-molding shrinkage, too short Hold (Pressure) Time leads to inconsistent shrinkage, deformation and larger variability in part dimensions.

9. AUXILIARY OPERATIONS

Recommendations on Regrinding Resin

The use of contamination free and uniformly reground Delrin® has minimal influence on mechanical properties and molding performance of standard grades (see details below). To regrind the material properly, the following should be considered:

- Do not regrind molded parts, sprues or runners that are discolored or splayed—these conditions may indicate that the resin was degraded during processing.
- Avoid accumulation of reground resin whenever possible by continuous reuse of sprues and runners. Ideally regrind at the molding machine and feedback immediately using a close loop system to avoid any contamination. If grinding is done in a batch process away from the molding machine, care should be taken to avoid contamination of sprues and runners. Protect reground resin from contamination and dirt by storing in clean, dry, clearly labelled, covered containers.
- Maintain a constant ratio of virgin to reground resin, and mix adequately prior to molding. A suitable ratio depends upon the quality of the reground resin and the requirements of the part. A ratio of 3 to 1 of virgin resin to reground resin is common, although larger quantities of reground resin can be used successfully
- Ideally use a low speed grinder, but higher speed grinders are acceptable if knives are well sharpened and if holes in the screen are large enough (4 mm [0.16 in]) to avoid fines. The grinder should be thoroughly cleaned before grinding a different material.
- Excessive fines should be removed.
- Avoid reprocessed resin from outside sources.
- For optimum properties of toughened grades, sprues and runners should be reground and used as soon as possible, as moisture pick-up is fast for these resins (See Section 3 – Drying Guidelines). The fraction of regrind for these compositions should not exceed 25% in the feed, and it should be fed immediately back into the hopper

Effect on Mechanical Properties

Table 9.1 displays the results of 10-pass regrind studies which has been run using either 100% or 50% regrind with standard Delrin® grades. A 10-pass 50% addition regrind study is equivalent to a molder continuously regrinding 50% of the shot weight. Excellent retention of mechanical properties is observed in these conditions.

Table 9.1 Regrind Effects on Properties of Standard Delrin® Grades

Number of Processings	10 x 100%	10 x 50%
Melt Flow Index	Change < 10%	Change < 2%
Tensile Strength at Yield	No Change	No Change
Notch Impacted Strength	Change < 20%	Change < 2%

Recycled material should have approximately the same size as fresh pellets or fresh granules. Grinder screens with a mesh size of about 5 mm (0.2 in) yield a grain size of approximately 3 mm (0.12 in) in diameter. A screen with a mesh of approximately 2.5 mm (0.1 in) can be used for removing dust particles in the regrind. Before processing, the regrind should be dried to avoid the possibility of degradation due to the presence of moisture.

Coloring

Delrin® is available in a range of standard and custom colors.

When molding natural Delrin® with a coloring system from a manufacturer other than DuPont, the following should be noted:

- The pigment or masterbatch manufacturer's safe handling procedures must be applied.
- Small scale tests should be run initially to check melt stability (See Section 7, foaming test), as some acidic, basic or metallic pigments will decompose Delrin®.
- Pigments usually affect the crystallization rate and consequently the shrinkage. Different coloring systems (even those giving the same color) could cause different shrinkages, as can be seen from **Figure 8.10**. Part dimensions should be checked in the small scale tests.
- The dry pigment or master-batch has to be chemically compatible with the base resin and must have good thermal stability above the processing temperature of the resin.
- The carrier can be considered as a surface lubricant, which may, theoretically, cause screw slippage leading to screw feed and/or filling problems.
- The key issue when adding color during molding is to ensure a homogeneous dispersion and mixing of the pigment in the polymer matrix.

When adding color during molding, one should observe the following points carefully:

- Use of a reasonable ratio between polymer and master-batch.
- Ideally use a screw with a mixing head, or alternately use of a high-compression screw.
- Use of a screw retraction stroke less than 30% of the maximum screw retraction of the machine.

Material Handling

Delrin® acetal resin is supplied as spherical or cylindrical pellets approximately 3 mm (0.12 in) in dimensions. They are packaged in moisture protected, tear resistant polyethylene bags. The bulk density of the unfilled resin granules is about 0.8 g/cm³.

Delrin® acetal resin is shipped dry and need not be dried before molding. Resin that has been stored in a cold warehouse area should be brought to room temperature prior to molding. This will prevent moisture condensation and variations in heat required to melt and thus in melt temperature.

Particular care is required for the toughened compositions of Delrin®. Bags of toughened grades of Delrin® should not be opened until they are ready to be used. If a bag is opened for any significant period of time and the resin has picked up moisture, the material should be dried before it is molded.

Pellets of Delrin® are surface lubricated to aid flow of pellets. Further lubrication of these compositions is not necessary.

Open containers of resin only in well-ventilated areas. Minimize the generation and accumulation of dust. Additives in this product do not present a respiratory hazard unless the product is ground to a powder of respirable size and the dust is inhaled. All dusts are potentially injurious to the respiratory tract if respirable products are generated and inhaled in sufficiently large concentration. Good execution of hygiene practices, as with all dusts, should include precaution to prevent inhalation of respirable particles.

10. TROUBLESHOOTING GUIDE

The following troubleshooting guide is meant to provide prioritized suggestions for the improvement of issues seen in plastic parts and their processing. Please identify the column representing the issue of concern and read down to each row of the suggested remedies in numerical order. It is often more practical to explore the sensitivity of a processing parameter like pack time first, before exploring a more time consuming and costly change in gate size, for example.

Troubleshooting Guide

Problem	Suggested remedies (listed in order of convenience)
Melt Quality Problems	
Mold deposit	<ul style="list-style-type: none">• Decrease injection fill rate• Check melt temperature and decrease to recommended target if melt temperature is high• Avoid resin contamination• Correct hold-up spots in cylinder, screw, nozzle assembly• Increase gate size, flare gate• Enlarge vents• Change vent location• Use hopper drier to improve the resin's thermal stability in extreme cases
Odor	<ul style="list-style-type: none">• Observe melt appearance (gassing) and measure melt temperature• Check melt temperature and decrease to recommended target if melt temperature is high• Avoid resin contamination• Reduce overall cycle to decrease holdup time• Correct holdup spots in cylinder, adaptor, nozzle, screw tip, and check valve assembly• Use smaller injection unit
Unmelted particles	<ul style="list-style-type: none">• Check melt temperature and increase to recommended target if melt temperature is low• Increase back pressure• Reduce screw rpm• Use hopper drier to preheat resin• Increase overall cycle• Use screw designed for Delrin®• Use larger machine or injection unit
Screw deposit	<ul style="list-style-type: none">• Lessen severity of screw (esp. for Delrin® 100 flow grades)—within recommendations• Avoid overcooling the feed throat• Check % of feed/transition/metering—within recommendations
Black spot or brown/yellow streaks	<ul style="list-style-type: none">• Decrease residence time in injection unit (smaller screw)• Avoid resin contamination• Correct holdup spots in cylinder, screw, nozzle assembly• Check hopper cooling (80–90 °C [176–194 °F])
Pigment streaks	<ul style="list-style-type: none">• Increase back pressure to improve dispersion• Use a mixing head screw• Evaluate other coloring systems• Evaluate fully precompounded color
Filling Problems	
Short shots	<ul style="list-style-type: none">• Maintain uniform pad• Repair leaking back flow valve if pad cannot be maintained• Increase injection fill pressure• Increase injection fill rate• Check melt temperature and increase to recommended target if melt temperature is low• Check mold temperature and increase to recommended target if mold temperature is low• Enlarge vents• Change vent location• Increase overall cycle• Use screw designed for Delrin®• Use larger machine or injection unit
Voids in parts	<ul style="list-style-type: none">• Increase hold pressure• Increase hold (pressure) time• Locate gate in thickest area• Decrease injection fill rate• Improve melt uniformity; check melt temperature and decrease to recommended target if melt temperature is high• Repair leaking back flow valve if pad cannot be maintained• Enlarge vents• Improve gate thickness or location• Eliminate any restrictions in runner or nozzle
Weak weldlines	<ul style="list-style-type: none">• Increase hold pressure• Adjust injection fill rate (around 1 s per mm of part thickness)• Check melt temperature and increase to recommended target if melt temperature is low• Enlarge vents• Check mold temperature and increase to recommended target if mold temperature is low• Avoid mold release spray• Change vent or gate location• Use larger machine or injection unit

Note: Minimize nozzle length when molding at or near limit of injection pressure capacity of molding equipment. This will be particularly true for Delrin® 100 type resins having high melt viscosity.

Troubleshooting Guide (continued)

Problem	Suggested remedies (listed in order of convenience)
Ejection Problems	
Part sticking in mold	<ul style="list-style-type: none">• Increase hold (pressure) time• Correct mold defects (undercuts)• Change or add ejector pin locations• Decrease hold pressure• Decrease injection fill rate• Increase cycle (possibly only temporarily)• Use mold release temporarily
Sprue sticking	<ul style="list-style-type: none">• Remove burrs on sprue• Correct alignment between sprue and nozzle• Radius sharp corners where the sprue meets the runner (or the part)• Increase hold (pressure) time• Increase nozzle temperature (190 °C [374 °F]), but avoid excessive temperature• Increase mold cooling time• Use nozzle orifice smaller than sprue bushing• Improve sprue puller• Increase taper of sprue• Use mold release temporarily
Dimensional Problems	
Shot to shot dimensional variations	<ul style="list-style-type: none">• Increase injection hold pressure• Maintain uniform pad (cushion)• Repair leaking back flow valve if pad cannot be maintained• Increase hold (pressure) time• Increase gate thickness and/or location• Maintain uniform cycle• Eliminate unmelted particles (see below)• Use larger machine or screw designed for Delrin®
Warpage	<ul style="list-style-type: none">• Check mold temperatures, balance temperatures, and adjust to recommended target• Locate gate in thickest area• Increase hold (pressure) time• Increase gate thickness and/or location• Round sharp corner• Clean water channels in mold; improve mold cooling system• Improve part design (e.g., avoid bottlenecks in melt flow)• Change or add ejector pin locations
Surface Problems	
Blush, frost and folds	<ul style="list-style-type: none">• Decrease injection fill rate• Check mold temperature and increase to recommended target if mold temperature is low• Change gate location
Gate smear	<ul style="list-style-type: none">• Decrease injection fill rate• Flare gate• Increase gate size• Change gate location
Jetting	<ul style="list-style-type: none">• Increase or decrease injection fill rate• Increase gate size, flare gate• Check mold temperature and increase to recommended target if mold temperature is low• Change gate location
Pits, orange peel, wrinkles	<ul style="list-style-type: none">• Increase hold pressure• Increase injection fill rate• Increase hold (pressure) time• Check mold temperature and increase to recommended target if mold temperature is low• Check melt temperature and increase to recommended target if melt temperature is low• Enlarge vents• Increase gate size
Sink marks	<ul style="list-style-type: none">• Repair leaking back flow valve if pad cannot be maintained• Increase hold pressure• Increase hold (pressure) time• Increase gate size• Change gate location• Check mold temperature and decrease to recommended target if mold temperature is high
Splay	<ul style="list-style-type: none">• Check mold temperature and decrease to recommended target if mold temperature is high• Avoid resin contamination• Decrease injection fill rate• Correct holdup spots in cylinder screw, nozzle assembly• Increase size of small gate

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